ECONOMIC GEOLOGY

VOL. XXV. MARCH–APRIL, 1930. No. 2

ORIGIN OF THE BOLEO COPPER DEPOSIT, LOWER CALIFORNIA, MEXICO.[1]

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INTRODUCTION.

THE Boleo Copper Deposit is located around Santa Rosalia, at approximately 27° 20′ N. latitude and 112° 20′ W. longitude, on

[1] Extract from a dissertation presented in June, 1927, to the Department of Geology of Stanford University as part requirement for the degree of Doctor of Philosophy.

[2] Fellow of the C. R. B. Educational Foundation, Inc., 1925–1927. The author is especially indebted to Prof. C. F. Tolman, Dr. H. W. Morse, Dr. A. F. Rogers, Mr. U. S. Grant, IV, who determined the fossils, and the staff of the Compagnie du Boleo.

the eastern coast of the central part of the peninsula of Lower California. (Fig. 1.)

Santa Rosalia, the center of the mining district, is a camp of 1,500 inhabitants. Small boats provide irregular service to Guay-

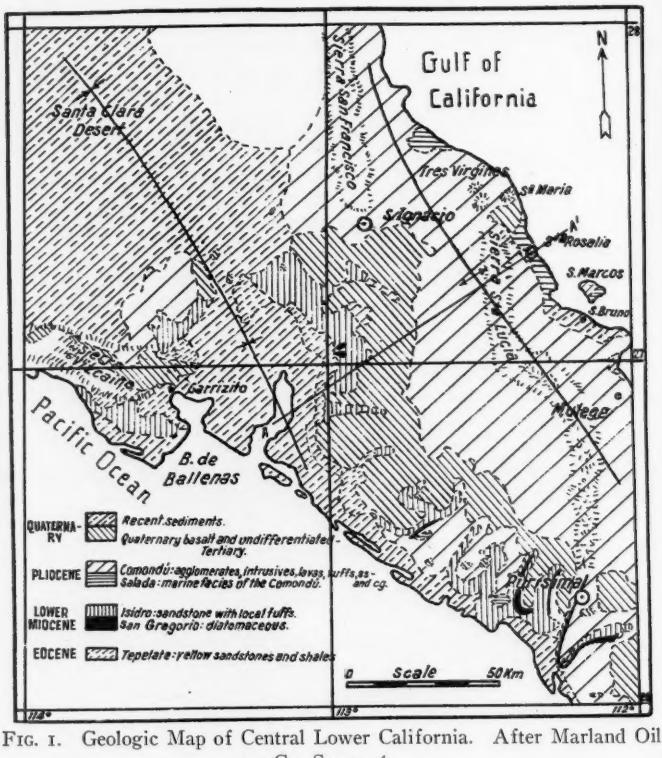

FIG. 1. Geologic Map of Central Lower California. After Marland Oil Co. Survey.[4]

mas, Sonora, La Paz, Baja, California, and Mazatlan Sinaloa. A few roads and trails lead inland.

Nelson [3] includes the Santa Rosalia district in the arid tropical

[3] Nelson, E. W., "Lower California and its Natural Resources," *Nat. Acad. Sci. Mem.*, vol. 16, 1st mem., 1921.

[4] Informe sobre la exploración geológica de la Baja California, por la Marland Oil Co. of Mexico, S. A.," *Bol. del Petróleo*, vol. 17, pp. 417–453, and vol. 18, pp. 14–53, 1924.

zone. The average summer temperature is 100° F.; frost never occurs and rainfall is irregular. Occasional cloudbursts give as much as eight inches of water but a complete absence of rain for two or three years is common. Desert conditions prevail over the country.

Vegetation is sparsely distributed. It includes several species of cacti, mesquites, acacias, and other tropical bushes, mostly thorny.

History of Mining.—The copper deposit consists of four main mineralized beds interstratified in a series of pyroclastic sediments.

The outcrops have probably been exploited for centuries by the natives. Various German groups mined the ore during the latter part of the 19th century and from them the "Compagnie du

FIG. 2. Section along *A–A'*, Fig. 1. After N. H. Darton.[5]

Boleo," organized in Paris in 1885, bought the concession. The name "Boleo" is derived from the appellation given by the natives to the small nodules of carbonate ore which were abundant in the oxidized zone. The rich oxidized ore is now exhausted and mining is concentrated below the water level in the sulphide zone of two ore beds. The Santa Rosalia Mine, or Rancheria, and the Montado or Providencia Mine exploit bed No. 1 by means of inclines. The Margarita or Purgatorio Mine and the Santa Rita Mine operate in bed No. 3, and are equipped with shallow vertical shafts. Modern methods, very similar to those of the European coal fields with thin seams, are used in all the mines.

The ore averages 4 or 5 per cent. of copper and is treated in the Santa Rosalia plant, which produces blister copper; this is

[5] Darton, N. H., "Geologic Reconnaissance in Baja California," *Jour. Geol.*, vol. 29, pp. 720–748, 1921. For the geology of the region see also: Heim, Albert, "The Tertiary of Southern Lower California," *Geol. Mag.*, vol. 59, pp. 529–547, 1922.

shipped to the United States where it is refined. The annual production since 1909 is approximately 12,000 metric tons of blister.

PHYSIOGRAPHY.

The Santa Rosalia District (Fig. 3) forms a typical Lower California mesa, characteristic of a young topography. The

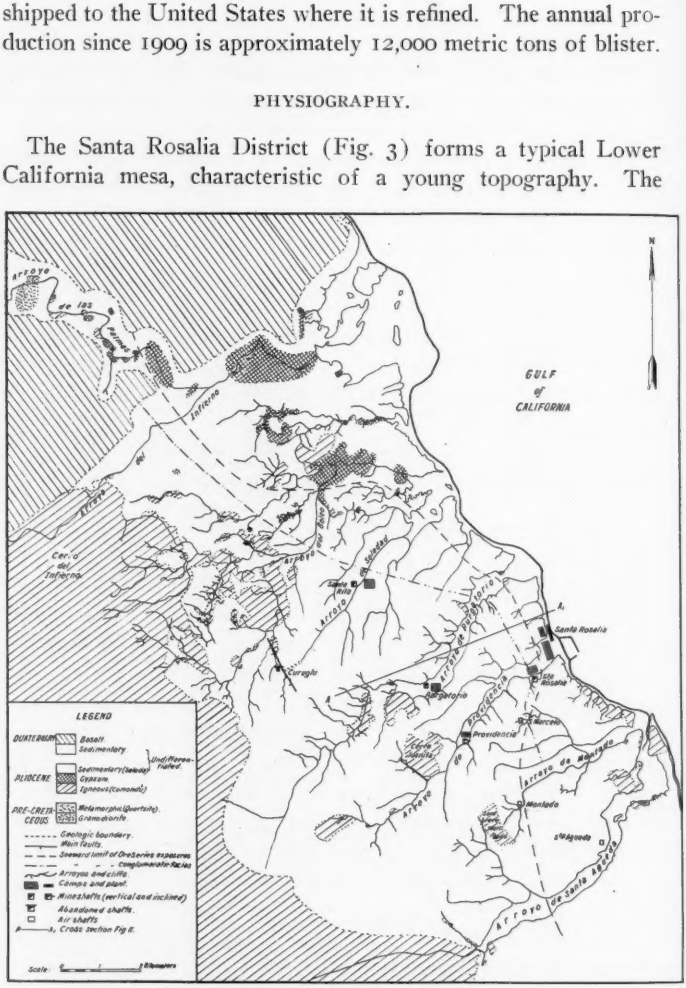

FIG. 3. Sketch map of the Boleo District showing drainage, geology, facies zones of the sediments, and the principal mines and camps. For cross section *A–A*, see Fig. 5.

surface, slightly undulated, slopes gently toward the southeast and is cut by numerous deep arroyos.

This plateau is limited to the southwest by the volcanic foothills of the Sierra Santa Lucia and to the northwest by the Tres Virgines and Santa Maria volcanoes. Toward the northeast, the mesa ends abruptly at the Gulf of Lower California with a steep slope or a cliff. To the southeast, on the contrary, the constant slope enables the plateau to grade into a Quaternary coastal plain near San Bruno (Figs. 1, 2, and 3).

In the mining district, the elevation ranges from 300 meters in the western part to 70–100 meters at the coast. The uniformity of the mesa surface is broken by a few hills of volcanic rocks emerging from the sedimentary series, as the Cerro Juanita and the Sombrero Montado. These hills were undoubtedly islands at the time of the deposition of the sediments. A Quaternary basalt cap covers the northwestern part of the region.

The arroyos run normal to the coast line with a gradient of 1 to 3 per cent., and are absolutely dry. Occasional cloudbursts create huge torrents, as shown by the alluvium. The valleys, usually wide in the sedimentary formations, are reduced to narrow gorges in the gypsum and lavas of the bed rock.

There are two distinct terraces along the arroyos showing that the present elevation is the result of the third uplift since the deposition of the lava cap. There are corresponding traces of wave-built terraces along the shore. The uplift was differential, causing a tilting from north to south as indicated by the gradual passage of the plateau into the San Bruno coastal plain.

GENERAL GEOLOGY.

Rock Formations.

The rocks of the Boleo District include a pre-Cretaceous granitic and metamorphic complex, Pliocene volcanic rocks, Pliocene to Pleistocene sediments, mostly pyroclastic and often underlaid by gypsum, and a Pleistocene lava flow partly covering the sediments. (Fig. 4.)

Old Complex.—Granodiorite outcrops in the Arroyo de las

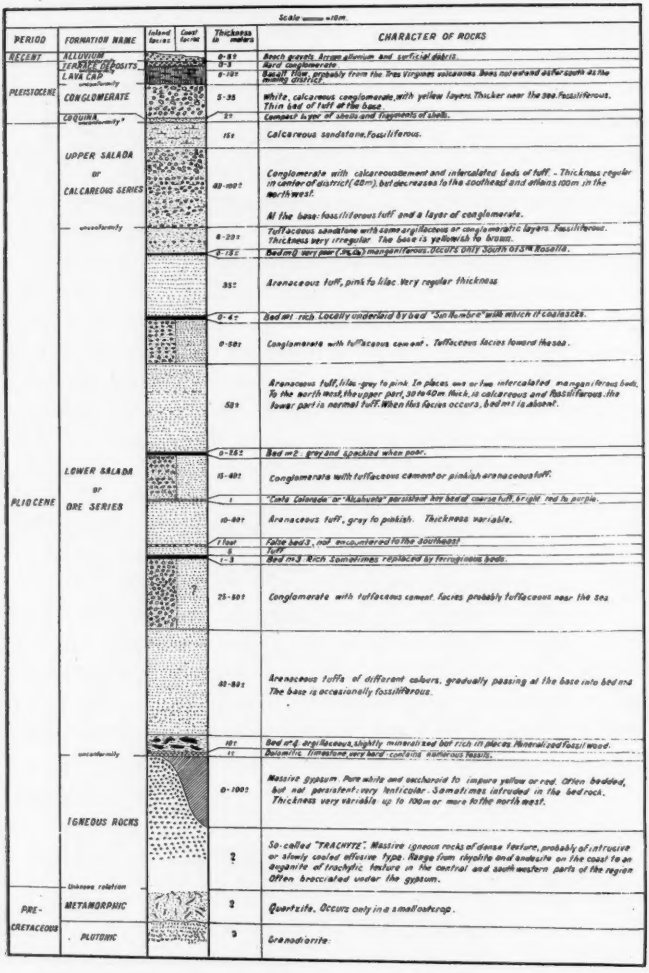
Scale ——— =10m.
PERIOD
FORMATION NAME
Inland facies
Coast facies
Thickness in meters
CHARACTER OF ROCKS
RECENT
ALLUVIUM
0-8?
Beach gravels. Recent alluvium and surficial debris.
TERRACE DEPOSITS
0-3
Hard conglomerate
LAVA CAP
0-10?
Basalt flow, probably from the Tres Virgenes volcanoes. Does not extend as far south as the Mulatos district.
PLEISTOCENE
unconformity
CONGLOMERATE
5-35
White, calcareous conglomerate with yellow layers. Thicker near the sea. Fossiliferous. Thin bed of tuff at the base.
unconformity?
COQUINA
2?
Compact layer of shells and fragments of shells.
15±
Calcareous sandstone. Fossiliferous.
UPPER SALADA or CALCAREOUS SERIES
40-100?
Conglomerate with calcareous cement and intercalated beds of tuff. - Thickness regular in center of district (40m), but decreases to the southeast and attains 100m in the northwest.
At the base: fossiliferous tuff and a layer of conglomerate.
unconformity
6-20?
Tuffaceous sandstone with some argillaceous or conglomeratic layers. Fossiliferous. Thickness very irregular. The base is yellowish to brown.
0-15?
Bed m4 very poor (2%Cb) manganiferous. Occurs only South of 3rd Fossella.
35?
Arenaceous tuff, pink to lilac. Very regular thickness
0-4?
Bed m1 rich. Locally underlaid by bed "San Nombre" with which it coalesces.
0-50?
Conglomerate with tuffaceous cement. Tuffaceous facies toward the sea.
50?
Arenaceous tuff, lilac-grey to pink. In places one or two intercalated manganiferous beds. To the north west, the upper part, 20 to 40m thick, is calcareous and fossiliferous. the lower part is normal tuff. When this facies occurs, bed m1 is absent.
0-15?
Bed m2 grey and speckled when poor.
LOWER SALADA or ORE SERIES
15-40?
Conglomerate with tuffaceous cement or pinkish arenaceous tuff.
1
"Caly Colorado" or "Alcahuela" persistent bey bed of coarse tuff, bright red to purple.
10-80?
Arenaceous tuff, grey to pinkish. Thickness variable.
1 foot
False beds, not encountered to the southeast
tuff
1-3
Bed m3 Rich. Sometimes replaced by ferruginous beds.
PLIOCENE
25-50?
Conglomerate with tuffaceous cement, facies probably tuffaceous near the sea.
40-80?
Arenaceous tuffs of different colours, gradually passing at the base into bed m4. The base is occasionally fossiliferous.
10?
Bed m4 argillaceous, slightly mineralized but rich in places. Mineralized fossil wood.
11
Dolomitic limestone very hard, contains auriferous fossils.
unconformity
IGNEOUS ROCKS
0-100?
Massive Gypsum. Pure white and saccharoid to impure yellow or red. Often bedded, but not persistent; very lenticular. Sometimes intruded in the bed rock. Thickness very variable up to 100m or more to the north west.
?
So-called "TRACHYTE". Massive igneous rocks of dense texture, probably of intrusive or slowly cooled effusive type. Range from rhyolite and andesite on the coast to an dogenite of trachytic texture in the central and south western parts of the region. Often brecciated under the gypsum.
Unknown relation
PRE-CRETACEOUS
METAMORPHIC
?
Quartzite. Occurs only in a small outcrop.
PLUTONIC
?
Granodiorite.

FIG. 4. Stratigraphic column of the Boleo Copper District.

Palmas at the northwestern limit of the district. It is grayish and speckled, has a holocrystalline coarse-grained texture, and is composed mainly of orthoclase, microcline, plagioclase, quartz, biotite and green hornblende. Apatite and primary magnetite occur as usual and there is a little secondary magnetite and sericite. Clinging to this plutonic core are small masses of pink, very hard, highly recrystallized quartzite, probably a sandstone affected by contact metamorphism. The smooth, rounded surface separating this complex from the overlying sediments indicates a long period of erosion.

These rocks are probably pre-Cretaceous, as are all the other granitic rocks forming the basal complex of the peninsula.

Gypsum.—Thick beds and masses of gypsum occur in many parts of the district at the base of the sedimentary series. It is most abundantly exposed to the north, where the maximum thickness attains about 100 meters. It is reported from several reconnaissant drillings but is conspicuously lacking over large areas. It is occasionally pure white and saccharoidal but generally impure and colored in various shades of yellow, brown, and red, due probably to ferric salts. It contains no anhydrite. It is usually found in imperfect lenticular beds lying directly on the lava forming the bed rock and following all its irregularities, but it forms also massive accumulations without apparent stratification and in two instances it is actually included within walls of lava.

The origin of this gypsum has been attributed to precipitation by evaporation in a partly enclosed body of water or to precipitation from hydrothermal submarine springs. The writer inclines toward the latter theory, by mingling of sulphate water with sea water, since an abnormal local concentration of calcium sulphate by hydrothermal springs accounts best for the erratic and varied distribution of the gypsum bodies.

Gypsum is also disseminated throughout the sedimentary beds of the district, showing that sulphate waters continued to circulate for a long period. There is no direct evidence of age; this formation has been included in the Pliocene with the adjacent rocks.

Salada Formation.—The Salada formation includes all the marine sediments deposited during the Pliocene period. In the Boleo District it is advisable to subdivide it into two series on the basis of lithological and paleontological differences. The lower portion, usually referred to as the Ore Series, has been termed Lower Salada, and the upper beds or Calcareous Series have been designated as Upper Salada. There are slight local unconformities between the Lower and Upper Salada but further detailed work is necessary to draw the line of demarcation between them and between the Upper Salada and the Pleistocene beds. The maximum thickness of the Salada attains 500 meters.

Lower Salada or Ore Series.—1. Dolomitic limestone: In several places a one-meter layer of dolomitic limestone occurs directly on the volcanic bed rock or on the gypsum. It is not continuous and according to the relief of the bed rock it may underlie ore bed 4, ore bed 3, and even ore bed 1, but in all cases it preceded the deposition of the pyroclastic sediments. The rock is brown, hard, and fossiliferous. It is composed of crystalline calcite and dolomite with some detrital feldspar and biotite. Secondary quartz, gypsum, and carbonates are common. The bedding follows all the irregularities of the bed rock and occasionally reaches 30°. Foraminifera are abundant and include *Triloculina,* suggesting shallow warm water.

2. Tuff: The oldest pyroclastic bed lying on the volcanic rock or on the limestone is ore bed 4 with its tuffaceous footwall. The upper portion of the bed, which is argillaceous, grades into a series of arenaceous tuffs. Similar tuffaceous groups, averaging 40 to 50 meters in thickness, overlie each of the ore beds. These sediments are well stratified and continuous, except in the vicinity of the main volcanic cores. If the core is small the beds pass over it; if it is more important some of the strata thin out and disappear as they rise along the bed rock (Fig. 5). Cross bedding is frequent in these cases.

These sediments are mostly pink to purplish in color, characteristic of basic tuffs. The rock is well consolidated, though not very hard, and is usually arenaceous. The texture is fine to

coarse; coarser and more lithic in the vicinity of the bed rock, and more argillaceous above the ore beds. The composition is that of augite-andesite, very similar to that of the underlying lavas. Labradorite is almost the only feldspar and occurs in phenocrysts and microlites. A pyroxene, probably diallage, is by far the most abundant ferromagnesian mineral although biotite, hornblende, and magnetite are frequent. Quartz and glass particles are rare. Chalcedony, chlorite, calcite, opal, needles of apatite, and small disseminated crystals of gypsum occur as secondary minerals. Epidote is also probably present. The pyroxene is partly altered to magnetite. Chalcocite and chalcopyrite are sparsely disseminated throughout the tuff.

Between ore beds 2 and 3 there is a peculiar thin stratum of bright red to purple coarse tuff, called "Cinta Colorada." It is the only reliable key bed in the formation.

3. Conglomerate: Volcanic conglomerate occurs in beds, twenty-five to fifty meters in thickness, just below the ore beds and above the tuff beds. The elements of the conglomerate are poorly sorted, ranging from pebbles to large boulders. They are subangular, and are more rounded to the southeast. Their composition varies; the lower beds contain mainly augite-andesite with some andesite and dacite, while higher up trachyte, rhyolite, and basalt are also present. The cement of the conglomerate is a typical crystal-lithic tuff with much augite-andesite. The secondary minerals are the same as in the tuff, mostly chlorite and chalcedony.

An interesting fact, mentioned by A. Locke in a private report, is the change of facies of these conglomerates toward the northeast, where they grade into real tuff. The limit of the conglomeratic facies indicates the direction of the shore at the time of deposition and is almost similar to the present coast line (Fig. 3).

Fossils of the Lower Salada were found in the tuff overlying the dolomitic limestone. They include *Pecten* (*Pecten*) *keepi* Arnold and *Pecten* (*Plagioctenium*) *circularis aequisulcatus* Carpenter, which suggests strongly that the formation is Pliocene as reported by the Marland Oil Co. survey. There are fossil wood and vegetal remains in the ore beds.

Although the bulk of the Ore Series is not fossiliferous, the continuity and the good stratification of the beds are evidence of their deposition under sea water. Moreover the fossils and the relation of the formation to the bed rock suggest shallow water and the poor assortment and poor rounding of the pebbles indicate rapid deposition near the source of the sediments.

Upper Salada or Calcareous Series.—This group of rocks is quite different from the Ore Series. It is less pyroclastic and more marine although it contains beds of pure tuff. The sediments are more loosely consolidated and very fossiliferous. The color is lighter, ranging from white to yellowish without any pink. The tuffs are calcareous and gypsiferous and less siliceous. The conglomerates have also a calcareous and gypsiferous cement. The pebbles and boulders contain all the rocks encountered in the Lower Salada and also fragments of more acidic types such as phonolites, rhyolitic perlites, and obsidian.

The series is limited by a layer of conglomerate at the botton and a bed of calcareous sandstone at the top. There are slight local unconformities between the Lower and Upper Salada as already mentioned. There are neither vegetal remains nor mineralized horizons in this formation.

The fossils collected included *Pecten* (*Plagioctenium*) *abietis* Jordan and Hertlein, *Pecten* (*Plagiocetenium*) *circularis aequisulcatus* Carpenter, *Pecten* (*Patinopecten*) *bakeri* Hanna and Hertlein, *Pecten cf. cataractes* Dall, *Panope aff. generosa* Gould, and *Ostrea palmula* Carpenter. This fauna is most probably Upper Pliocene.

Pleistocene Sediments.—The Upper Salada is covered by a thin bed of coquina and a thick bed of conglomerate with calcareous cement. This conglomerate is white with yellow layers and very fossiliferous. Its thickness increases toward the sea into which the beds plunge. The composition is similar to that of the Upper Salada members. The occurrence of a thin bed of tuff between the coquina and the conglomerate indicates a remnant of volcanic activity.

There is apparently no unconformity between these beds and the Upper Salada but the abundant fauna of the youngest con-

glomerate is typically Quaternary and includes even Mammoth remains.

The terrace deposits are composed of an indurated conglomerate averaging three meters in thickness. The cement is calcareous and siliceous.

Igneous Rocks.—Excepting the pre-Cretaceous granodiorite, all the igneous rocks of the Boleo District are volcanic. Neither dikes nor veins have been found. The lavas include the Lower Pliocene bed rock and the Pleistocene basalt cap.

"Bed Rock."—The outcrops and the underground workings show that the bed rock forms a continuous basin in which the sediments were deposited. Protruding masses formed submarine hills and islands, rarely brecciated. The rock is rather massive, with occasional lenses of tuff. These lavas are variegated, showing mostly dark shades of gray, red, yellow, brown, and green. They are mostly basic and crystalline, but glassy acidic types occur near the shore.

Fuchs[6] called this rock labradorite or "trachyte peu acide," others call it andesite and the local French name is "trachyte." But the bulk of the rock is composed of augite-andesite, which has a flow structure and is sometimes scoriaceous and vesicular. The texture is precrystalline, micro-aphanitic, with seriate porphyritic fabric.[7] It is also trachytic, as the feldspar laths are arranged in flow lines. The diameter of the phenocrysts is generally smaller than one millimeter.

The main feldspar is an acid to medium labradorite: the highest extinction angles obtained on sections at right angle to the twin lamellation range from 28° to 36°. The albite twinning is general. Zonal banding is common, with the more basic plagioclase toward the center of the crystals. Pyroxene is by far the most abundant ferromagnesian mineral. It is a light colored variety, probably diallage. It occurs in euhedral crystals often showing twinning, and in the groundmass. Other primary min-

[6] Fuchs, Ed., "Note sur le gîte de cuivre du Boleo," *Soc. Géol. France Bull.*, 3d series, vol. 14, pp. 79–92, 1886.

[7] Cross, Iddings, Pirsson, and Washington, "The Texture of Igneous rocks," *Jour. Geol.*, vol. 14, pp. 692–707, 1906.

erals are magnetite and apatite. Biotite and quartz are exceedingly rare.

The rock does not seem to have undergone much alteration. The feldspars are slightly zeolitized, the pyroxenes are almost fresh. Olivine was not found but there are some hexagonal and prismatic crystals of iddingsite, suggesting replacement of olivine. This is rather exceptional as residual olivine should be present. However it does not imply a strong alteration because olivine is probably always the first mineral to be replaced even in the later stage of cooling.[8] There is much secondary magnetite, some secondary apatite needles and a fibrous cryptocrystalline mineral, possibly tremolite.

An important character of the augite-andesite is its tenor in copper which averages 0.2 per cent. This tenor is very high and as there are no sulphides in the rock it can best be explained by the great percentage of pyroxene in which the copper is probably concentrated as silicate.[9]

Part of the lavas may have been erupted in the basin itself as suggested by some brecciated cores resembling volcanic necks, but most of the augite-andesite probably came from the foot of the Sierra Santa Lucia (Figs. 1 and 2), which is certainly the source of the pyroclastic sediments as indicated by the facies lines of the conglomerate. The complete absence of any sign of contact metamorphism in the overlying beds and the transgressive character of the latter on the volcanic cores show clearly that the igneous rock was not intruded, but was deposited before the Ore Series, probably in the Lower Pliocene, as the volcanic activity of the peninsula began only at the end of the Miocene period.

Basalt Cap.—The northwestern part of the district is covered by a basaltic lava cap about ten meters in thickness. The source of this lava is undoubtedly the Tres Virgines volcanoes, which are apparently extinct at the present time. Zeolitization of the feldspars is very pronounced in places and probably took place soon after deposition. It seems to indicate that the lava was laid

[8] Ross, C. S. and Shannon, E. V., *U. S. National Museum, Proc.*, vol. 67, art. 7, 1925.

[9] Lindgren, W., "Mineral Deposits," 2d ed., pp. 426 and 431, 1919.

down in water.[10] This basalt cap overlies unconformably the Pliocene and Pleistocene beds. On the other hand it extends across some of the main arroyos. It was thus deposited in the sea just before the uplift which marked the end of the Pleistocene period.

STRUCTURAL GEOLOGY.

Folding.—The average dip of the sediments is 5° east to southeast, slightly greater than the slope of the mesa. In the vicinity of the volcanic cores the lowest beds thin out and the dip increases up to 30° but this is due to differential compaction.[11] Close to the shore, the dip of the beds increases to 20° as they plunge into the sea (Fig. 5). The axis of this monoclinal fold is parallel to the coast. This structure is very likely the result of the uplift.

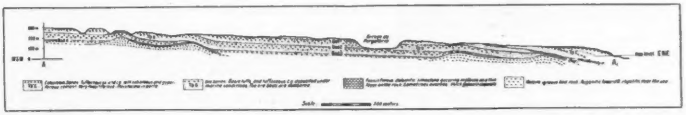

FIG. 5. General cross section W.S.W.–E.N.E. across the central part of the district, showing position of ore beds, irregularities of bed rock and dip, change of facies of conglomerate and monoclinal fold along the coast. See Fig. 3.

Faulting.—Faults are very numerous but quite small. Only one important fault is known, and this has a throw of 60 meters. The dip is almost vertical, and the downthrown side is to the west. The strike varies between N.–S. and N. 45° W., which is the general trend of the Lower California fractures. None of the faults are mineralized and there is no sign of enrichment in their vicinity below the water level. The faulting may have taken place at different times but most of it was accomplished after the deposition of the Pleistocene beds.

[10] Lindgren, W., ECON. GEOL., vol. 6, pp. 693–694, 1911.

[11] Nevin, C. M. and Sherrill, R. E., "Studies in Differential Compaction," *Bull. Amer. Assoc. Petrol. Geol.*, vol. 13, pp. 1–22, 1929.

HISTORICAL GEOLOGY.

It appears from the preceding description that the history of the Boleo Copper District begins in the Lower Pliocene, with the land extending over the present emplacement of the Sierra Santa Lucia and the sea occupying the area now covered by the deposit, with a few islands of old pre-Cretaceous rocks. A long period of volcanic activity started near the shore whereby great quantities of lava poured into the sea, building up a basin with irregular bottom and protruding islands.

A second phase of volcanism introduced calcium sulphate solutions in certain points in the basin, resulting in the precipitation of thick gypsum lenses. The hydrothermal waters were much less active in later times. A short period of calm must have followed, indicated by the fossils in the dolomitic limestone and the vegetal matter of ore bed 4.

The third stage of volcanism was the eruption of successive flows of pyroclastic material. There were four recurrences of the same phenomenon, marked first by an outburst of volcanic ash which became tuff, then by a flow of mud which formed the conglomerate. Each of the eruptive periods was succeeded by a short period of quiescence, indicated by the vegetal debris in the clayey ore beds forming the base of the tuffaceous groups. A subsidence must have accompanied this stage as the fossils do not suggest a sea as deep as the thickness of the deposit. An uplift marked the end of this stage and erosion was permitted to act for a short time, causing local disconformities between the Lower and Upper Salada.

A gradual subsidence followed and marine beds were accumulated during the end of the Pliocene and during the Pleistocene. A little volcanic activity still persisted as shown by a few beds of tuff and by the basalt flow from the Tres Virgines.

Finally came the Late Pleistocene uplift which was more accentuated in the northern part of the district and caused the faulting and folding of the region. This uplift had two periods of rest, allowing terraces to be formed at two different levels.

THE ORE BEDS.

Occurrence and Distribution of the Ore.—In contrast with the tuff and the cement of the conglomerate, both of which are sandy, the ore beds are of clayey material with patches of tuff and conglomerate, partly altered. The beds lie on the conglomerate layers, either directly or with intercalation of a layer of very fine tuff, the "falso piso," and they pass gradually into the tuff forming the hanging wall. The ore is not distributed uniformly but occurs in banded zones, nodules, and shoots, which gradually become poorer toward the walls of the bed. Although the mineralization is irregular within the bed, it persists generally over the whole area covered by the layer. When the bed is interrupted the mineralization disappears also. The ore is mashed and slickensided, and when it is mined it is pushed forward by its internal pressure. These characters seem to indicate that the ore beds are layers of altered clayey tuff.

Bed *o* is mostly manganiferous and poor in copper (0.5 per cent.). Its thickness averages 1 to 1.5 meters. It is limited to the east corner of the district. To the west it grades into an unmineralized layer of conglomerate and its extension is limited by erosion.

Bed 1 is rich and its workable thickness varies from 1 to 4 meters. In the vicinity of a volcanic hill, the Sombrero Montado, it is underlain by another bed called "Sin Nombre" which joins bed 1 as they both die out against the igneous rock.

Bed 2 is usually poor. Its thickness ranges from 0 to 2.5 meters. It seems to be more siliceous than the other beds and it was particularly rich in "boleos" in the oxidized zone.

Bed 3 is the richest and also the most interesting. It is, in places, replaced by a ferruginous facies. In the Santa Rita mine the ore is extremely variable in aspect and composition. The thickness of the workable part averages 2 to 3 meters.

Bed 4 is almost 10 meters thick and shows very plainly the transition between the compact clayey ore and the unaltered tuff. It is rather low grade but contains lenses of rich ore. Mineralized fossil wood is abundant. This bed does not extend over

large areas because it covers the bottom of the basin of sedimentation and is limited by the protruding volcanic masses (Fig. 5).

Several slightly mineralized manganiferous horizons occur between beds 1 and 2. In beds 1 and 3 richer zones have been found in the vicinity of the main augite-andesite hills, as for example, the Sombrero Montado and the Cerro Juanita. These zones are roughly parallel to the facies lines of the conglomerate, as pointed out by Locke in his private report. The limits of the mineralized area are not yet determined.

Composition and Texture of the Ore.—The very interesting oxidized zone, now practically exhausted, will not be considered in the present paper, which is mainly concerned with the genesis of the primary deposit below the water level, where the ore minerals are sulphides with the exception of a little native copper and a few oxidized copper minerals occurring in the vicinity of faults.

The main sulphide, chalcocite, occurs disseminated in the clayey ore, which appears usually black, gray, or bluish. In places it is quite variegated, as in the Santa Rita mine, where green, pink, and brown ores are found intimately associated. The bottom of the mineralized part of the beds is commonly rich in limonite and consequently brownish.

Peculiar structures and black inclusions indicate the presence of vegetal debris which is also common in thin sections.

The ore is soft and unctuous: it is easily polished with the nail and some varieties called "jaboncillo" are quite soapy. Most of the ore, particularly the jaboncillo type, exhibits an enormous adsorptive capacity for water. This is probably due to the extreme fineness of the clay particles and their easy cleavage and felt-like arrangement, which suggests one-dimensional colloidal particles as supposed by Wherry for bentonite.[12]

The ore contains a water content reaching 35 to 40 per cent. In the specimens fresh from the mine the hygroscopic moisture alone attains almost 30 per cent. After long exposure to the air this amount drops to an average of 15 per cent., half of which can be regained overnight by a specimen dried at 110° C.

[12] Wherry, E. T., *Am. Mineralogist*, vol. 10, p. 120, 1925.

Table I gives average percentages of the main constituents of the ore mined in 1926.

TABLE I.

COMPOSITION OF ORE.

SiO_2	27.14	
Al_2O_3	8.36	
$FeO + Fe_2O_3$	5.96	
MnO	3.74	very variable.
CaO	2.99	in calcite and gypsum
MgO	3.37	mostly in chlorite.
Cu	4.92	mostly in chalcocite.
SO_3	0.55	in gypsum, barite, etc.
S	1.65	in sulphides.
NiO, CoO, ZnO	0.56	
H_2O at 110° C.	± 27.00	
Loss on ignition	10.26	

The loss on ignition includes water of crystallization, carbon dioxide from the carbonates, and organic matter. More detailed investigation is still necessary along this line. The composition does not vary much from one mine to another. The ratio of silica to alumina ranges from 2.5 : 1 to 3.5 : 1. The copper content may be very high in places as there are rich nodules but the average tenor of the ore brought from the mines does not exceed 5 per cent. Silver is present at the rate of 125 grams per metric ton and traces of gold have been detected. Photographic tests did not reveal the presence of radioactive elements.

Thin sections of the ore show clearly that it is an altered argillaceous tuff. The shaly unmineralized footwall of bed 1 is a good example of this alteration. The crystalline character of the tuff is marked. Some residual euhedral or subhedral feldspar is still present but shows a progressive change to chlorite. With the exception of the feldspar, a few mica flakes, some chlorite grains, and some apatite needles, the whole mass is an aggregate with cryptocrystalline texture. Chalcocite is scattered throughout the aggregate, either in euhedral crystals or in anhedral grains. Residual feldspar, apatite needles, and flakes of a residual dark pleochroic mica are sparsely distributed.

Fig. 6 illustrates a rich ore characterized by complete altera-

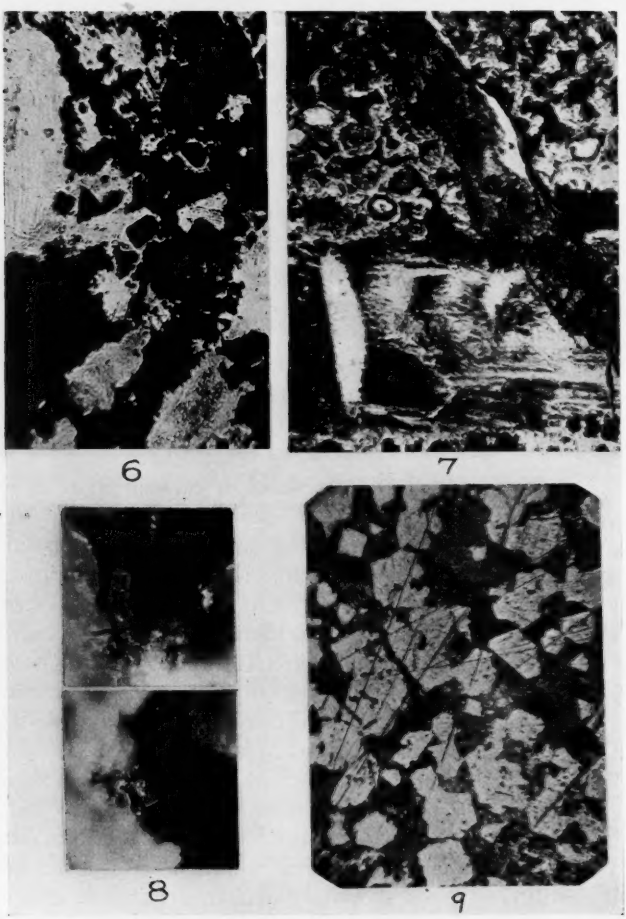

FIG. 6. Thin section of a rich Santa Rosalia ore. Chalcocite (black) forms a compact mass between pseudomorphic areas suggesting feldspar laths, now a mixture of chlorite and calcite (small grains with high relief). Euhedral crystals of chalcocite are also present. × 225.

FIG. 7. Thin section of mineralized wood; white areas, chalcedony; black spots, chalcocite and melaconite. The shaded parts along the fibers are colored by organic matter. The veinlet cutting the specimen is filled with azurite and chrysocolla. × 125.

FIG. 8. Crystals of heulandite on wires of crystalline native copper. × 20.

FIG. 9. Polished section showing usual habit of chalcocite crystals. × 125.

tion, but the original crystalline texture is preserved by the pseudomorphic appearance. The gangue minerals, mostly chlorite and calcite resulting from the breaking down of the feldspars, occupy prismatic areas strongly suggesting feldspar laths. Chalcocite forms a compact mass between the pseudomorphic areas but does not penetrate them. This last feature is characteristic for the whole deposit. The completely altered ore is commonly rich in calcite.

In many instances the ore appears to be the altered equivalent of a lithic tuff. The rock fragments are usually little altered and unmineralized and the alteration is complete in the clayey cement in which vegetal fragments and chalcocite are scattered.

A rarer but interesting type of ore which occurs mostly in beds 3 and 4 is composed of mineralized fossil wood (Fig. 7). The wood is entirely chalcedonized and the ore is disseminated along the fibers.

In summary, it may be stated that the mineralized part of the beds is a clay composed of cryptocrystalline minerals resulting from the alteration of argillaceous tuff. The mineralization is limited to the groundmass of the rock; phenocrysts and rock fragments are altered but not mineralized.

MINERALS PRESENT.

Only the minerals encountered in the unoxidized ore beds below water level are mentioned here. The cryptocrystalline size of the particles and the difficulties encountered in the preparation of thin sections of standard thickness made the study of the gangue minerals an extremely arduous problem. The list is incomplete.

Gangue Minerals.

Chalcedony.—The presence of chalcedony in the Boleo ore was first mentioned by P. Krusch [13] who considered it the main mineral of the groundmass. It is certainly abundant and was probably generated by the alteration of silicates.

[13] Krusch, P., "Ueber eine Kupfererzlagerstätte in Nieder-Californien," *Zeit. f. Prakt. Geol.*, vol. 7, pp. 83–86, 1899.

Opal occurs sparsely below the water level; it is abundant in the oxidized zone.

Limonite is very common and in places occupies the whole bed. It is commonly disseminated between the ore or concentrated at the foot of the bed, and is probably the result of hydration of magnetite and iron-bearing silicates.

Psilomelane?—The manganese of the ore is very likely present in the form of psilomelane and other hydrous oxides.

Calcite occurs in small masses and in minute grains disseminated throughout the aggregate. Its occurrence in the pseudomorphic chlorite (Fig. 6) proves it to be secondary. It is irregularly distributed. Magnesite is probably also present.

Feldspar.—The feldspars which were the main primary constituents of the tuff are scarce in the ore beds and occur only as residual grains partly altered to chlorite. Part of the feldspars may also have been altered to zeolites.

Pyroxene is rare in the ore beds; it is the probable source of the chlorite.

Hornblende is very rare and occurs as residual grains.

Epidote?—This mineral has not been recognized with certainty but is strongly suggested by the color of certain elements of the aggregate.

Zeolites.—In the " falso piso " of bed 3 in the Santa Rita mine small cavities were found to contain numerous beautiful microscopic crystals of heulandite associated with crystalline native copper (Fig. 8).

Heulandite occurs here in prisms flattened parallel to (010) and elongated parallel to the *a* axis: this is a rare habit, as it is usually elongated parallel to the *c* axis. The most common form is a simple prism with the faces (201) and ($20\bar{1}$). The face (110) is also common and (021) is rarer. Similar crystals have been described from Balhennan Hill in Stirlingshire, Scotland.[14]

In the Boleo crystals the plane of the optic axes is nearly parallel to *c*. The (010) faces under crossed nicols show con-

[14] Goldschmidt, V., Atlas der Krystallformen," Bd. IV., Taf. 89, Text p. 138, 1918.

spicuously the division into four segments giving an hour-glass structure. The cleavage parallel to (010) is prominent. The crystals occur isolated, twinned, or in groups, and are accompanied by other zeolites, one of which is probably brewsterite, and by small hexagonal plates of kaolinite.

Zeolites are very likely also disseminated in the groundmass of the ore and may be due to the hydration and desilication of feldspars.

Mica.—The ore contains a few residual flakes of a partly altered pleochroic mica, probably biotite.

Chlorite is, with chalcedony, the most common constituent of the gangue. It occurs in places in small masses but more often is disseminated in the cryptocrystalline aggregate or in small particles bordering residual crystals of feldspars. It is probably derived in part from a combination of the constituents of the feldspars with those of ferromagnesian minerals,[15], and in part from direct hydration of biotite and hornblende, and from hydration, oxidation, and desilication of pyroxene.[16] The products of the alteration are chlorite, epidote, calcite, magnesite, chalcedony, and hematite which alters easily to limonite. These changes are usually considered as the result of hydrothermal action and are accompanied by a considerable increase in volume.

Kaolinite occurs in small hexagonal crystals with the zeolites and is also probably disseminated in the clayey aggregate, as may be inferred by the generally low double refraction and index of refraction of the groundmass.

Beidellite?—The gangue and especially the "jaboncillo" contain a clay mineral which strongly suggests beidellite although the birefringence is rather low.[17] This substance is accompanied by another mineral, probably not clay, that occurs in fan-shaped groups of micaceous plates and strongly resembles cookeite, ac-

[15] Iddings, J. P., "Rock Minerals," 2d ed., p. 477, 1911.

[16] Van Hise, C. R., "A Treatise on Metamorphism," U. S. Geol. Survey Mon. 47, pp. 275 and seq., 1904.

[17] Ross, C. S., and Shannon, E. V., "The Minerals of Bentonite and Related Clays and their Physical Properties," *Jour. Amer. Ceramic Soc.*, vol. 9, no. 2, pp. 77–96, 1926.

cording to Dr. C. S. Ross.[18] X-ray analyses will be necessary to identify these minerals with certainty.

Apatite is found as usual in small secondary needles.

Barite and Celestite are present in most of the ores. Barite is quite common in some parts of the Santa Rita mine.

Gypsum is disseminated in fine crystals in the ore beds, as well as in the rest of the sediments.

Ore Minerals.

Native Copper.—Occurs in crystals, lamellae, and grains associated with zeolites. It is often concentrated in small fissures and large nodules are found. It is abundant only in the Santa Rita mine, where it amounts to 15 per cent. of the ore minerals. It is also present in the sulphide ore as minute disseminated grains but it shows no relation whatever with the sulphides except in a few instances where it seems to result from the breaking down of bornite.

Chalcocite.—This is by far the most abundant sulphide; it forms 90 per cent. of the ore minerals. It is present under different forms.

The most common mode of occurrence is in very fine, apparently shapeless grains or in extremely fine needles or prismatic crystals disseminated in the cryptocrystalline aggregate of gangue minerals (Fig. 10). It is quite remarkable that the sulphide is only found in the groundmass and does not penetrate the pseudomorphic areas left by former phenocrysts and rock fragments. (See also Fig. 6.)

Larger euhedral crystals commonly occur. The most usual sections are hexagons, commonly with unequal sides, rhombs with opposite angles often slightly truncated, and triangles, also with truncated angles (Fig. 9). These pseudo-hexagonal forms of chalcocite are not rare [19] and are due to stellate twinning of orthorhombic crystals. These crystals are important because they

[18] Personal communication, 1928.

[19] Goldschmidt, C., *op. cit.*, Bd. V., Atlas Taf. 38, 39, and 40.

represent the typical habit of the orthorhombic low-temperature form and must have been developed below 91° C.[20]

Another mode of occurrence of chalcocite is in massive form. These masses are characterized by the presence of whitish areas in the generally more bluish mineral, although massive white chalcocite is also common. These masses are the result of accretion of chalcocite on the initial grains and needles as illustrated by Fig. 10, and can thus be considered as secondary. According

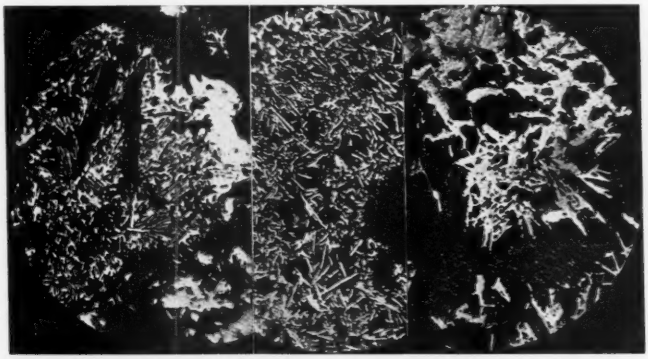

FIG. 10. Polished sections illustrating the growing of massive chalcocite (white) by accretion on primary crystals. × 270.

to Schneiderhöhn[21] the bluish color of chalcocite is not due to the internal properties of the mineral and can be removed by polishing. The author cannot accept this view: it is true that long polishing makes the surface lighter but the blue chalcocite remains of a deeper hue, which is probably due to an admixture of a little iron or bornite.

The cuprous sulphide is also found in aggregates of chalcocite, bornite, and chalcopyrite grains or in rims bordering residual cores of chalcopyrite and very rarely around residual bornite.

[20] Posjnak, E., Allen, E. T., and Merwin, H. E., "The Sulphides of Copper," ECON. GEOL., vol. 10, pp. 513, 523, 1915.

[21] Schneiderhöhn, H., "Anleitung zur Mikroskopischen Bestimmung, etc.," p. 210, 1922.

This chalcocite, which is apparently secondary, belongs to the bluish variety. Finally, chalcocite also occurs in the fibers of chalcedonized wood as mentioned above.

Covellite occurs in small quantities and always in needles penetrating chalcocite or in small masses associated with it. In all cases it seems to replace chalcocite.

Bornite is found in pseudomorphic crystals, partly or completely replacing chalcocite. It appears also in irregular masses around residual chalcocite. Furthermore, as already mentioned, it is found in aggregates with chalcocite and chalcopyrite and probably in traces in the secondary blue chalcocite. It occurs, in places, around residual cores of chalcopyrite.

Chalcopyrite occurs as residual areas in grains of bornite or chalcocite and also, more commonly, it replaces bornite or chalcocite. It occurs also disseminated as mentioned above.

Pyrite is extremely rare in all the rocks of the district.

Cuprite, Melaconite, Malachite, Azurite, Chrysocolla, Atacamite, are found only as oxidation products in the vicinity of the oxidized zone or near faults where oxidizing waters can circulate. They are the main minerals of the oxidized zone, where they are associated with some rare lead-copper minerals such as boleite, and cumengite, but they are outside the scope of this study.

Cobalt, Nickel, Zinc, and Silver are present in small quantities as indicated by chemical analysis. However, the microscopic investigation failed to detect any of their typical minerals. They are probably included as impurities in chalcocite or in other minerals.

Paragenesis of the Ore Minerals.

The paragenesis of the ore minerals can be clearly deduced from the occurrences described.

Practically all the chalcocite below water level is primary (i.e. it is not a replacement mineral). Its presence in idiomorphic crystals proves that it does not replace another mineral, moreover, secondary sulphides do not occur as disseminated grains in an argillaceous gangue except by replacement of pre-existing sulphides, and in this deposit the deep levels are as rich as those

near the water table. The extreme fineness of the grains suggests that the chalcocite was first precipitated in colloidal form and passed later into the stable crystalline condition.[22]

The larger crystals and the compact masses are the result of accretion of second generation cuprous sulphide on the nuclear crystals and grains, as shown by the experiments of Clark.[23] (See Fig. 10.)

The first evidence of metasomatic replacement is given by bornite, which is here unquestionably a later mineral as it is found replacing crystals of chalcocite. No bornite originally deposited directly as bornite could be found. The replacement of chalcocite by bornite is rare; the contrary is observed in most cases. However, the copper sulphides are convertible one into another and bornite replacing chalcocite has already been described.[24]

Chalcopyrite is probably also entirely later and, for the greater part, was formed after bornite, because it replaces both chalcocite and bornite, a common result of the action of cold descending ferrous solutions.[25] But bornite is also found replacing chalcopyrite and there is a third generation of chalcocite, of the bluish variety, which replaces chalcopyrite and bornite.

Covellite replaces chalcocite as usual. In one instance it was found in bornite but occupying probably the place of former residual chalcocite. Covellite is the first sign of the beginning of oxidation.[26] In places it is found directly preceding cuprite and melaconite. Most of these secondary minerals were found close to the zone of oxidation.

Native copper is the only ore mineral whose relationship to

22 Doelter, C., "Ueber die Umwandlung amorpher Körper in Kristallinische," *Zeit. f. Chem. und Indus. der Kolloide*, Bd. 8, Heft 1, p. 29; Heft 2, p. 86, 1911.

23 Clark, J. D., "A Chemical Study of the Enrichment of Copper Sulphide Ores," Bull. Univ. of Mexico, No. 75, p. 122, 1914. Tolman, C. F., Jr., and Clark, J. D., "The Oxidation, Solution and Precipitation of Copper in Electrolytic Solutions," Econ. Geol., vol. 9, p. 578, 1914.

24 Beeson, J. J., "The Disseminated Copper Ores of Bingham Canyon, Utah," *Am. Inst. Min. Eng. Bull.* 107, p. 2231, 1915.

25 Rogers, A. F., "Origin of Copper Ores of the 'Red Beds' Type," Econ. Geol., vol. 11, p. 379, 1916.

26 Schneiderhöhn, H., *op. cit.*, p. 223.

others remains quite uncertain. In one specimen from the Montado mine, near the oxidation zone, it was found in specks on the edge of a grain of bornite. This is quite common in the oxidized zone of copper deposits. But in the Boleo district the most important occurrence of native copper is in the Santa Rita mine, well below the zone of oxidation. It is associated and contemporaneous with zeolites and does not show any relation to the sulphides.

Rôle of Water.

Connate Water.—A great amount of connate sea water must have been retained by the sediments at the time of deposition and circulation certainly followed, during which the saline water mixing with probable magmatic emanations of the tuff acted as a good agent of alteration, dissolution, and migration of the minerals.

Hydrothermal Water.—Hydrothermal activity is indicated by the chlorite, which, however, may have been formed by the reagents produced during mineralization.

Vadose and Ground Water.—The water table rises slowly from 0 at the shore to 25 meters at the Santa Rita and Purgatorio mines, with a general dip of 0.8 per cent. In the zone of saturation, the descending meteoric waters mixed with the connate waters and contributed to the reactions which brought the primary chalcocite and native copper into their present state but the position of the water table never played a rôle in the precipitation of the primary minerals because the deep levels where these minerals are found have remained below water table ever since the deposition of the beds.

In the vicinity of the water table, bornite, chalcopyrite, secondary chalcocite, covellite, cuprite and malaconite are found as intermediate stages of oxidation, and in the zone of aeration the ore is composed of carbonates, and silicates which resulted from the reworking of the initial ore by vadose water.

ORIGIN OF THE DEPOSIT.

Present State of the Problem.—Fuchs summarized as follows the genesis of the deposit:[27] quiet eruptions of volcanic mud in the

[27] Fuchs, Ed., *op. cit.*

bottom of a lagoon in which were deposited regular beds of tuff. This phenomenon was interrupted four times by minor uplifts, accompanied by intrusions of "trachyte," and the fissures formed during those movements permitted the arrival of hydrothermal solutions of copper, iron, and manganese, which spread in the beds. The primary ore mineral was chalcopyrite. This syngenetic theory is not satisfactory because a submarine eruption would have produced very irregular beds with strong cross-bedding and the solutions which formed the upper beds must have passed through the underlying sediments, whereas there is no trace of any mineralized fissure in the deposit. Furthermore it is now clear that there is no primary chalcopyrite in this deposit.

De Launay, who had to adopt Fuchs' views in their joint treatise,[28] expressed his own opinion in the book which he published alone.[29] According to him the tuff was deposited as an ordinary sediment and the ore beds are the result of a "chemical concentration of sulphides derived from the destruction of the igneous rocks or of the ore minerals they contained." He also supposes that the first sulphide to form was chalcopyrite. The idea about the origin is rather vague though probably true in its principle. He means apparently that the copper was leached from the country rock and carried in solution to the sedimentary beds. He does not mention how the concentration was made and whether it occurred at the time of deposition or later.

Krusch[30] and Weed[31] suggested ordinary hydrothermal mineralizing solutions coming through the bed rock and spreading along the beds. This leads also to unsatisfactory conclusions. As there is no sign that the solutions crossed the sediments they must have come through the igneous rock in veins reaching the highest beds of the Ore Series, otherwise the mineralization of the upper beds could not be explained. This leads to the conclusion that the cupriferous solutions arrived either through the

[28] Fuchs, Ed., and de Launay, L., "Traité des gîtes minéraux et métallifères," vol. 2, pp. 339–349, 1893.

[29] de Launay, L., "Gîtes minéraux et métallifères," vol. 2, p. 791, 1913.

[30] Krusch, P., *op. cit.*

[31] Weed, H. W., "The Copper Mines of the World," p. 246, 1907.

main foothills (Cerro del Infierno) or through the group of hills formed by the Cerro Juanita and Cerro Montado (Fig. 3). In the first case rich ore would be found in the southwestern part of the district where the solutions must have flowed; but this is not true. In the second case the ore found northwest of these hills could not be explained because the general dip is, and always was, toward the southeast. Moreover, the underground workings penetrating the bed rock have never encountered a mineralized vein. The uniformity of the mineralization over wide areas is another argument against this theory; if the cupriferous waters came from a main feeder vein they would have flowed along the lines of maximum slope, forming a fan-shaped deposit. Concentrations would occur on the landward side of the volcanic cores because the counter slope would cause the solutions to become more or less stagnant. But this has not been observed; the richer zones are often on the seaward side of the cores and are more related to the facies of the sediments.

Source of Copper.—As a syngenetic hypothesis is not valid and as a hydrothermal hypothesis does not account for some typical characteristics of the deposit, the source of the copper must be sought in the sedimentary rock itself. This is a modification of De Launay's idea of a chemical concentration of copper contained in the country rock.

The evidence that the copper is derived from the tuff is as follows:

(1) The tuff is similar in composition to the augite-andesite of the bed rock except that it contains very little copper, whereas the augite-andesite contains 0.2 per cent., probably in the pyroxenes.

(2) It is reasonable to suppose that the tuff contained originally also 0.2 per cent. of copper.

(3) The amount of copper concentrated in the ore beds is exactly what would be expected if the tuff contained originally 0.2 per cent. of copper. Supposing, very conservatively, that each bed contains two meters of 5 per cent. ore and was fed by 70 meters of sediments it is found that 0.06 per cent. copper may still be present in the tuff.

(4) The great uniformity of the mineralization coincides with the uniformity of the sedimentary beds.

(5) Richer ore is found in zones parallel to the facies lines of the conglomerate, that is, parallel to the lines of variation of the tuff.

(6) The deposit is much poorer inland, where the conglomerate prevails over the tuff. The copper was much more easily extracted from the fine grains of tuff than from the pebbles, as the water circulated more easily through the tuff than through the pebbles.

(7) It is easily conceivable that the connate and ground waters could extract the copper from the pyroxenes.

(8) It is equally conceivable that the copper in solution migrated downward to the argillaceous beds and was precipitated as chalcocite. The possibility of primary chalcocite in Red Beds from descending solutions was recognized long ago.[32]

Precipitation of Chalcocite.—Connate and ground waters slowly leached the copper from the tuff. Copper chloride may have been generated at the beginning but most of the copper was probably transported as sulphate, as indicated by the presence of barite. Downward migration of the copper was hindered by the obstacle of the impervious clay beds but the dip probably allowed sufficient movement to revive constantly the concentration of the solution in contact with the clay beds, in which the copper must have penetrated by diffusion, as suggested by the work of Liesegang,[33] Watanabe,[34] Whitman,[35] and others. The patterns of Fig. 10 are indeed very suggestive of a precipitation by diffusion in the groundmass of the beds. Only one mineral is precipitated and in small disseminated grains. Watanabé attributes monomineral dissemination to the presence of very small

[32] Lindgren, W., Graton, L. C., and Gordon, C. H., "The Ore Deposits of New Mexico," U. S. Geol. Surv. Prof. Paper 68, pp. 77–78, 1910.

[33] Liesegang, R. E., "Geologische Diffusionen," 1913.

[34] Watanabé, M., "Some Problems of Diffusion, with Special Reference to the Study of Ore Deposits," Tôhoku Imperial Univ., Sci. Rept., ser. 3, vol. 2, pp. 105–183, 1924.

[35] Whitman, A. R., "Diffusion in Ore Genesis," Econ. Geol., vol. 23, pp. 473–488, 1928.

scattered cavities where the ore mineral can be deposited more freely because of the smaller stress. His experiments show that precipitation takes place in small cavities even when the surrounding portion is almost free from precipitate.

The initial agent of deposition was probably the organic matter of the beds, which generated hydrogen sulphide, or some organic sulphur compound remaining occluded in the groundmass of the clay. The diffusing copper could be precipitated by these reagents as a colloidal gel in the small cavities of the diffusion medium. The fact that the groundmass alone played a rôle in the deposition is well shown by the absence of sulphides in the pseudomorphic areas. (Fig. 6.) The first mineral formed was probably cupric sulphide according to the reaction:

$$CuSo_4 + H_2 = CuS + H_2SO_4,$$

but, as shown by Clark,[36] the cupric sulphide is not the stable form, and gives chalcocite:

$$2CuS = Cu_2S + S.$$

This sulphur itself is capable of precipitating new chalcocite.

In the plastic medium composing the ore beds, the crystallization power of the ore mineral permitted the development of crystals and small masses by accretion and displacement of the surrounding material. The acid generated by the reaction mentioned above produced an intense rock alteration.

Precipitation of Native Copper.—As described above, the native copper is associated with zeolites. Its occurrence in crystals and lamellae occupying small cavities and fissures indicates that it has an entirely different origin from the chalcocite and that it was brought by percolating solutions instead of by diffusion.

The association of native copper, copper sulphides, zeolites, and chlorites in basic lavas and tuffs is found all over the world. In most cases native copper is predominant but the sulphides may also be abundant and carbonaceous matter is often present. The zeolitization of the Boleo tuff seems thus to have been caused by the same agents that acted on the copper-bearing amygdaloid

[36] *Op. cit.*, pp. 106–113 and 128.

lavas. These rocks were deposited in sea water and the zeolitization may have taken place soon after deposition under the influence of connate water and gas. The tuff was perhaps hot at the time of deposition, like the tuff of the Valley of Ten Thousand Smokes in Alaska [37] but this does not seem necessary as zeolites have a wide range of temperature of formation and, as Lane says,[38] the heat retained is not as important as the original chemical composition.

It is difficult to explain why the zeolitization is far more developed in the Santa Rita mine than in the rest of the deposits, but the process of zeolitization of basic lavas is itself still mysterious.

The mode of precipitation of the native copper is not much better known. Lane [39] considers that copper and iron are extracted from their minerals as chlorides and he suggests the following reactions:

$$2FeCl_2 + 2CuCl_2 = Cu_2Cl_2 + 2FeCl_3,$$

$$2FeCl_2 + 2CuCl + 3CaSiO_3 = 2Cu + Fe_2O_3 + 3SiO_2 + 3CaCl_2.$$

Nishio,[40] noticing the presence of carbonaceous matter with the native copper of the Nonesuch formation, made some experiments which tend to prove that copper sulphate can be reduced to native copper by organic compounds, as had already been pointed out by Rassenfosse.[41]

On the other hand, the crystals shown in Fig. 8 seem to indicate that the copper and zeolites were simply deposited from a solution saturated with them. There might be primary and secondary copper and zeolites.

[37] Fenner, C. N., "Origin and Mode of Emplacement of the Great Tuff Deposit in the Valley of Ten Thousand Smokes," *Nat. Geog. Soc.*, Tech. Paper, Katmai Ser., No. 1, 1923.

[38] Lane, A. C., "The Theory of Copper Deposition," Michigan Geol. Survey, Ann. Rept. for 1903, p. 248, 1905.

[39] Lane, A. C., "Native Copper Deposits," *Canad. Min. Inst., Jour.*, vol. 14, pp. 316–322, 1911.

[40] Nishio. K., "Native Copper and Silver in the Nonesuch Formation, Mich.," Econ. Geol., vol. 14, pp. 324–334, 1919.

[41] Rassenfosse, A., "Sur une formation nouvelle de cuivre colloidal," *Acad. Roy. Sci. Belgique Bull.* 1910, p. 738.

Enrichment.—The phenomena of enrichment which occurred near the water table and provoked the precipitation of bornite and chalcopyrite, presents the usual features of such deposits. This enrichment is only the prelude of the great oxidation which characterized the district.

CONCLUSION.

The Boleo Copper Deposit consists of four main mineralized clay beds, regularly interstratified in litoral volcanic tuffs and conglomerates of Pliocene age. The copper was extracted from the pyroxenes of the tuff by connate waters and migrated toward the clay beds as a sulphate or chloride solution. The copper penetrated into the clay by diffusion and was precipitated as chalcocite by the probable action of hydrogen sulphide or some other compound derived from the organic matter included in the clay. The disseminated specks of chalcocite grew into crystals and masses on account of their power of crystallization and the plasticity of the surrounding medium. Native copper was also precipitated in some parts of the district in conditions as yet little known. As the Quaternary uplift brought the ore near the water table, some slight secondary enrichment occurred, soon followed by an intense oxidation as the beds rose in the zone of aeration.

The deposit is hard to classify, as it pertains both to the "Red Beds" type and to the "native copper with zeolites in basic lavas" type. However, it can be defined as a stratified deposit of primary chalcocite and native copper, formed by concentration of copper contained in the surrounding rocks by means of circulating waters.

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BORNEO, D. E. I.

TIN–BEARING PEGMATITES IN EASTERN MANITOBA.

DUNCAN R. DERRY.

INTRODUCTION.

CONSIDERABLE interest has recently been aroused by the discovery of cassiterite in the Shatford Basin area of Manitoba. During the summer of 1929 active development work was carried on by several companies.

The district is 80 miles northeast of Winnipeg and adjoins the Manitoba-Ontario boundary. Most of the claims staked for

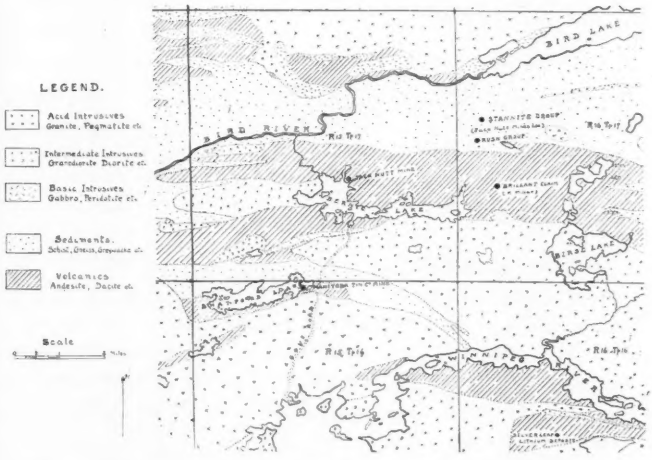

FIG. 1. Central part of Shatford Basin area. After J. F. Wright.

tin lie between the Winnipeg River to the south and the Bird River to the north.

The district may be reached by any one of the following routes: (1) By canoe or motor boat from Pointe du Bois, travel-

ling up the Winnipeg River for 9 miles to a point on the north bank from which a Government road has been built to Shatford and Bernic lakes. (2) From the town of Lac du Bonnet, across the lake of that name by launch, and up the Bird River by canoe. (3) By Western Canada Airways from Lac du Bonnet, landings being made on Bernic and Shatford lakes when the water is not too low.

Cassiterite was first discovered by Mr. K. Miller on a small island on Shatford Lake, now the property of the Manitoba Tin Company. Later Mr. Miller found cassiterite showings at several places around Bernic Lake, and interest having been aroused, a number of other finds were soon reported. During the summer of 1929 surface work was done on properties all around these finds; and on two properties, that of Jack Nutt Mines at Bernic Lake and the Manitoba Tin Company at Shatford Lake, shafts have been sunk to over 100 feet.

GEOLOGY.

The geology of this area has been well and fully described by J. F. Wright [1] in his report on the Bird River area, consequently no attempt will be made here to deal with the detailed petrology. The rocks and their chronological order given by Dr. Wright are briefly as follows:

Quaternary	Glacial	Gravel, sand, boulder clay
Pre-Cambrian	Plutonic Intrusives	Pegmatite
		Microcline granite and granite gneiss
		Oligoclase granite and granodiorite
		Diorite, syenite, granodiorite porphyry, and quartz porphyry
		Gabbro and amphibolite
		Amphibole peridotite
	Sedimentary-Volcanic Complex	Arkose, quartzite, and graywacke, apparently conformable with trachyte, dacite and andesite
		Quartz-mica schist with local conglomerate beds.

[1] J. F. Wright, "The Oiseau River Area, Southeast Manitoba," Geol. Surv. Canada, Summ. Rept., Part B, 1924.

In the sedimentary volcanic series, the volcanics seem definitely to correspond in age with the Keewatin of the Lake of the Woods district in Ontario. On the tin properties they are principally andesites, grading into a gabbroid phase which, in places, may be intrusive. The sediments of the series are of two types. The first, which may in part be older than the volcanics, consists of highly metamorphosed schists and gneisses, composed largely of quartz and mica, with scattered conglomerate beds carrying pebbles of an older granitic rock. The second type, which seems to be younger than the volcanics, is made up of finer material, graywacke, quartzite, slates, and similar sediments. The latter beds may belong to a later period than the rest, but no definite unconformity has been found separating them. Some sedimentary beds are found interbedded with the volcanics.

Intruding all the above rocks is an igneous series ranging from ultra-basic to acid. The ultra-basic phases are probably the oldest but as they occur only to the north of the Bird River, and not on any of the tin properties visited, they are of interest in this problem only in that, taken with the other intrusives, they show the high degree of differentiation that has occurred in the igneous rocks of this district. Next in age are intermediate intrusives comprising diorite, granodiorite, feldspar porphyry and gray oligoclase granite. All these appear to be phases of the same magma and seem to have been intruded about the same time. The third type of major intrusion is the red acid granite, the predominant feldspar being microcline, although plagioclase is abundant in parts of it, and it frequently carries biotite. This eruptive cuts all previously mentioned rocks. The relations of this granite to the intermediate intrusives generally are seen as numerous dikes of red pegmatitic granite, increasing in number towards the main mass of red acid granite, with inclusions of the intermediate intrusions. This red granite is regarded as being the later and main phase of the intrusive batholith that produced the intermediate types. Farther east in Ontario, nearer the center of the batholith, the acid granite can be seen to grade into a gray granodiorite in several places.

The last phase of igneous activity was the widespread intrusion of pegmatite dikes, sills, and masses. These intrude the volcanics, sediments and intermediate intrusives as dikes with sharp boundaries, but they occur in the red acid granite only as irregular segregations or rough, small dikes with indefinite boundaries. They are, therefore, taken by Dr. Wright as being the minor intrusive phase of the red microcline granite. It is possible however, that some of the pegmatites, for example those on the northwest shore of Bernic Lake, are the products of a smaller scale differentiation of the gray oligoclase granite or granodiorite lenses. This conclusion is suggested by the fact that the pegmatites in this part carry abundant albite. The intermediate intrusive lens at the west end of Bernic Lake is predominantly sodic and shows, within the mass, differentiation from the normal granodiorite to aplite and quartz-porphyry. However, as an albite-rich pegmatite is nowhere seen in contact with a pegmatite carrying pure potash feldspar, a difference in age cannot be proved.

The forms taken by pegmatites include dikes from a few inches to a hundred feet wide; flat-dipping sills, sometimes showing anticlinal, or even dome structure; irregular lenses; and stringers running off from the main masses.

The common minerals of the pegmatites are quartz, microcline, orthoclase, albite, muscovite, biotite, and tourmaline. More patchy in occurrence are cassiterite, garnet, beryl, fluorite, spodumene, lepidolite and amblygonite.

CHARACTERISTICS OF THE CASSITERITE.

The cassiterite is a dark, opaque type, showing none of the translucent brown crystals that are often seen in specimens from other parts of the world. It occurs in coarse, fairly well formed tetragonal crystals, horizontal striations on the pyramidal faces being particularly well developed. A slightly metallic lustre is sometimes seen in fresh specimens. Where the crystal form is not well developed and weathering has dulled the lustre, the cassiterite may be distinguished with difficulty from the black

tourmaline with which it is commonly associated. They may be distinguished by tapping the crystal with the point of a pick; the cassiterite powders to a brown color, whereas the tourmaline powders to a bluish or greenish gray.

In cases of doubt, cassiterite may be distinguished from all other minerals by placing the crystal in question in contact with zinc and covering it with cold hydrochloric acid (10 per cent.). The nascent hydrogen produced by the action of the acid on the zinc collects on the crystal. If it is cassiterite the hydrogen combines with the oxygen of the cassiterite, reducing the surface to a coating of metallic tin. This is dull gray at first but when washed and polished with a dry cloth, the bright metallic tin color is seen. In place of hydrochloric acid, sodium bisulphate [2] may be used. This can be carried dry and dissolved in water when needed, but in this case the acid must be heated to obtain the desired action.

EXAMPLES OF CASSITERITE SEGREGATIONS.

At first sight the cassiterite appears to occur quite irregularly throughout the pegmatite, but a study of a number of occurrences permits some generalizations, which can be best pointed out by giving a description of some of the more important segregations.

Shatford Lake.—The Shatford Lake deposit was the first discovery of cassiterite of any importance. It was found by Mr. K. Miller on a small island near the southeast corner of the lake, about 100 feet from the present shaft of the Manitoba Tin Company. Owing to its being almost level with the lake, the showing was covered with water after a few charges of dynamite had been put in. From the fragments seen, the segregation of cassiterite seems to have been at the contact of two phases of the pegmatite, a pink feldspathic phase and a quartz-muscovite phase (mistakenly called greisen).

Mr. H. Johnson, who saw the showing soon after discovery, informed the writer that the dike was about 3 feet wide and dipped south. The segregation occurred near the hanging wall,

[2] Ellsworth, H. V., *Canadian Mining Journal*, vol. 50, No. 16, 1929.

with the quartz-muscovite phase of the pegmatite nearer the center of the dike.

The country rock is andesite lava which is intruded by a large mass of pink acid granite, the contact of which lies a few hundred yards south of the lake. An intermediate intrusive mass lies to the north of the lake.

Nearby a number of sulphide veins have been found in the andesite. They contain pyrite, pyrrhotite, arsenopyrite, chalcopyrite and sphalerite in a gangue of red garnets, biotite, quartz and a little beryl. Only traces of tin have been found in the veins. These veins appear to be slightly later than the pegmatites, since in one or two places in the latter, small spots of pyrrhotite and chalcopyrite are found. These sulphides occur quite differently from the cassiterite. Stringers of them run off along crystal boundaries or eat into the feldspar, strongly suggesting replacement. The sulphide veins are rather closely associated with zones of garnets embedded in biotite. The origin of these garnet zones, or "garnet dikes" as they are locally called, is rather obscure; they may be traced for some distance along the strike and are, in places, about 100 feet wide. Dr. Wright has suggested that they may be metamorphosed ash beds. As these zones appear to have acted as channels for uprising solutions depositing the sulphides mentioned above, it was considered possible by some of the companies interested, that they might also have served as channels for tin-bearing solutions. Up to the present, however, no tin has been found in them.

North Shore of Bernic Lake.—Jack Nutt Mines Limited have sunk a shaft on which they are still working and have done much surface trenching on a group of claims on the north shore of Bernic Lake near the west end. Here cassiterite segregations occur at several places in pegmatites which cut andesite or its coarser gabbroid phase. The pegmatite is in dikes dipping in general about 45° northeast, though in one case 60° south. The strike of the dikes is very irregular. At one place just west of the shaft, a dike makes a sharp turn of 100°. From these, smaller sills of pegmatite run off with a very low dip. The rich-

est segregation seen is in one of these sills from a foot to eighteen inches thick, which at the surface, where the segregation occurs, is almost horizontal and appears to have taken the form of a gentle anticline (Fig. 2). The chief concentration is at the apex of this anticline. The western and more flat-lying limb has been eroded, but when the eastern limb is followed down as it dips into the greenstone, the cassiterite decreases, a few crystals only occurring near the hanging wall. Besides quartz and feldspar

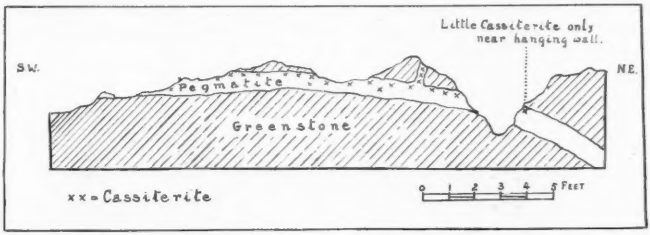

FIG. 2. Section through small pegmatite sill, Jack Nutt Mine, Bernic Lake.

the pegmatite also carries yellow muscovite, pink garnet, and black tourmaline, the latter segregated near both the hanging and footwalls in prisms lying with their long axes normal to the walls. Several 10-ton samples from this segregation have been run through the test mill on the property under the direction of Mr. A. C. Burnett, and have yielded from 1.5 per cent. to 2.0 per cent. of tin. This ore is commercial grade if sufficient quantity can be found.

Diamond drilling on these claims reveals a pegmatite body about 250 feet from the surface, apparently sill-shaped and about 250 feet thick. As far as can be learned from drill cores, the lower 100 feet is coarse quartz-feldspar pegmatite, and the upper 150 feet consists of a variety of types. These include a fine aplitic phase with albite, beryl, and quartz; a coarser radiating type with plagioclase feldspar akin to albite and identified by Dr. T. L. Walker as cleavelandite, associated with quartz and muscovite, and a third type rich in colorless spodumene. Fine grains of

cassiterite occur at a number of places in the upper half, mainly in the finer-grained types. Tourmaline was not seen in the upper part of the mass, but is quite abundant in the coarse, more normal pegmatite on the lower 100 feet. As yet not enough is known about the shape of the mass to draw any definite conclusions as to differentiation.

Stannite Claims.—These claims, recently taken over by Jack Nutt Mines, Limited, lie about one and a half miles north of the east end of Bernic Lake. One showing is of particular interest in indicating the relation of cassiterite segregations to the peg-

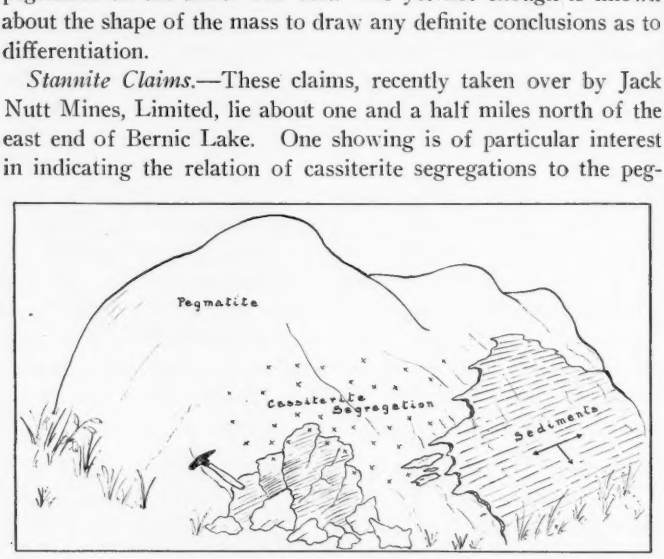

FIG. 3. Sketch of an outcrop on the Stannite claims, showing a cassiterite segregation near the hanging-wall of a pegmatite dike.

matite (Fig. 3). The outcrop is part of a pegmatite dike that strikes east-west and dips north 30° to 40°. The country rock here is a fine-banded graywacke and this forms the hanging wall, lying on part of the north side of the outcrop. Over the rest of the northern face of the outcrop, the graywacke wall has just been removed by erosion, leaving the uppermost part of the pegmatite exposed. Over this face cassiterite is abundant in large crystals embedded in quartz and muscovite with subordinate feldspar. On the south side of the outcrop, nearer the footwall (the footwall itself is covered over with drift) the pegmatite is barren of cassiterite and contains more feldspar than that on the north

side. In other words, the cassiterite, together with predominating quartz and muscovite, lies in a shallow zone next to the hanging wall of the dike. No cassiterite was seen in the sedimentary wall itself. A shallow hole blasted into the northern face of the pegmatite shows a decrease in cassiterite towards the center of the dike. A larger mass of pegmatite probably connected with this outcrop, and dipping in the same direction, appears 100 yards to the east. Here the cassiterite is seen in only a few spots, and these were all near the hanging wall. Another lens of pegmatite and aplite, not seen by the writer, lies a quarter of a mile north-

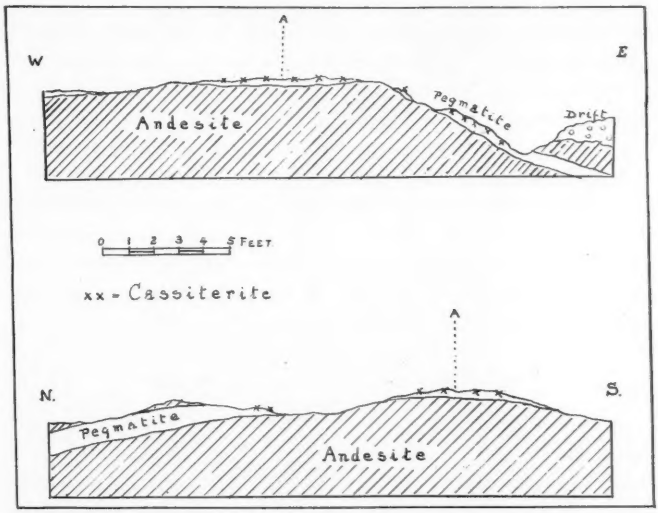

FIG. 4. Sections through a partially eroded pegmatite sill, Brillant claim.

east of the last, and is reported to have cassiterite fairly evenly distributed over the whole outcrop.

Rush Claims.—This group lies immediately south of the Stannite Group and it is controlled by the same company. Most of the workings are on a large pegmatite dike about 100 feet wide, dipping steeply to the north. Cassiterite occurs in this, but is

very patchy and seems to follow no definite rule. This is typical of the more steeply dipping masses.

Brillant Claim.—This claim, together with several others adjoining it, is owned by Mr. K. Miller and lies east of the northeast bay of Bernic Lake. The best showing seen was in a pegmatite sill varying from a foot to a few inches in thickness. It dips under the andesite to the north at about 15° and to the east at about 40° (Fig. 4). To the west and south most of the pegmatite has been eroded, but what is left suggests that the whole formed a gently domed structure. In the center, the pegmatite lies almost horizontal, forming a skin over the andesite, which is revealed in patches where the pegmatite has been completely worn through. Cassiterite segregations, with tourmaline, occur in the horizontal " skin " in the center and in the easterly dipping limb. In the latter the cassiterite seems to be more abundant near the hanging wall, but the sill is so thin that it is difficult to make a definite statement on that point.

The continuation of the eastern limb was covered by drift, but the northern limb was followed for a short distance down the dip, where the cassiterite decreases and disappears. This occurrence shows strikingly the segregation of cassiterite at the apex of a dome-shaped sill.

MICROSCOPIC EXAMINATION OF ORE.

A fairly typical specimen of tin-bearing pegmatite from a cassiterite segregation from Jack Nutt Mines claims on the north shore of Bernic Lake, shows in thin section, quartz, orthoclase, albite, cassiterite, tourmaline, garnet, and apatite. Tourmaline is in well-formed prisms, strongly pleochroic from pale gray to deep blue. It appears to have been the first mineral to form as one of the original constituents of the pegmatite. No evidence was seen to suggest that either tourmaline or cassiterite came in later by replacement as is often seen in tin associations of the pneumatolytic vein type. The cassiterite under plane polarized light is deep reddish brown with lighter buff-colored patches. Zoning is well shown and twinning is quite common. In many

cases small tourmaline prisms are partially or entirely enclosed in cassiterite, suggesting that the latter is the younger of the two (Fig. 5). In one section however, grains of cassiterite were

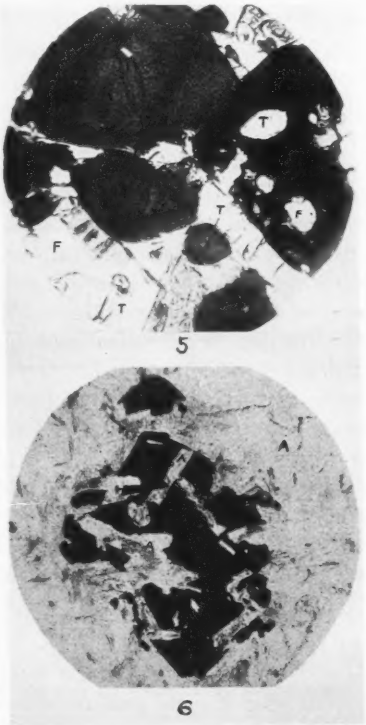

FIG. 5. Photomicrograph of tin-bearing pegmatite, Bernic Lake, showing cassiterite (*C*), tourmaline (*T*), with feldspar and quartz. (*F*). × 35.

FIG. 6. Photomicrograph of aplitic phase of pegmatite, showing laths of albite (*A*) partially enclosed in cassiterite (black). × 50.

seen enclosed in tourmaline. It is possible, therefore, that the period of tourmaline crystallization began before that of cas-

siterite but continued on after the latter was finished. One section from the pegmatite cut by the diamond drill, on the Bernic Lake property, shows unusual features. The cassiterite has crystallized later than the albite feldspar and laps around the short rectangular crystals of the latter (Fig. 6). This is difficult to explain and is quite contrary to the general rule for the district, but it may be due to some volatile element holding the tin in solution until a lower temperature than usual had been reached. Garnet was nowhere seen in contact with cassiterite, but it surrounds prisms of tourmaline and is, therefore, probably later than both cassiterite and tourmaline.

Quartz and feldspar fill cracks in the tourmaline, cassiterite and garnet and, except for the unusual case mentioned above, seem to have been the last minerals to form. In the sections described, which were taken near cassiterite segregations, orthoclase is subordinate to albite. No definite microcline was seen. The albite is well formed and seems to be primary, not formed, as is sometimes the case, by replacement of potash feldspar. It commonly contains rounded inclusions of quartz in the form of an intergrowth.

Muscovite in flakes and bunches evidently crystallized before most of the quartz and feldspar, but after the other minerals.

GENERAL RELATIONS OF TIN DEPOSITS TO PEGMATITES.

From the number of cassiterite occurrences in the district it can be concluded that the magma of the intrusive series was stanniferous in some degree. Also the extreme rock types, ultrabasic to acid, indicate that a high state of differentiation was reached. As is well known, the most favorable places for tin mineralization are around the contacts of granite domes, the highest points in the underground surface of the granite batholith. Owing to the great age of the rocks here, those highest domes have been removed by erosion, but it is reasonable to suppose that, since the magma was stanniferous, there was tin mineralization around these domes. Around the contact of the granite masses at the horizon now reached by erosion, little or no sign of pneu-

matolysis is apparent. Therefore, it is not probable that a search for veins of the granite border type, as seen in Cornwall, Saxony, and elsewhere, would meet with any great success. The sulphide veins near Shatford Lake are not thought to be of this type but were probably deposited at a slightly later period than the pegmatites, as suggested above.

If we consider that the vein type of tin mineralization of the upper horizon has been removed, the surface has now reached the pegmatite horizon. It should be noted that the difference between tin-bearing pegmatites and tin veins of the fissure or replacement type is one of degree and not of kind. In other parts of the world every gradation between the two can be found.[3] At the stage found in Manitoba, the tin has not been completely differentiated from the rock-forming minerals; it has only been partially concentrated by being left in the residual pegmatitic magma. But, within the individual pegmatite masses, there has been differentiation on a smaller scale. The examples from occurrences described above show that in all cases where the cassiterite is richest, it lies in the uppermost part of the mass, either in the hanging wall of the body or where a thin sill takes the form of an arch. It is suggested that the same principles apply here as in the case of the large-scale concentration at the tops of granite domes, where the tin-bearing solutions that were probably gaseous rose to the highest points possible. Whether the tin in these smaller pegmatite masses was deposited directly from gases or from liquid solutions is uncertain, but there is no evidence to suggest that the tin was deposited by replacement after the solidification of the rest of the pegmatite. It would seem, rather, that the tin-bearing solutions were intruded together with the rest of the pegmatite magma, but by reason of their greater mobility and lower specific gravity (due to the association with volatile elements), they rose to the highest points possible while the magma was still in a viscous state. The cassiterite crystals have not grown to the hanging wall, they merely lie near it. If they were among the first crystals to form, had the pegmatite magma been

[3] Jones, W. R., "Tin-fields of the World."

fluid, they would have sunk. We must, therefore, postulate a viscous magma for their support until the quartz and feldspar solidified.

In the case of a vertical or steeply dipping dike the distance for the upward migration of the tin compounds might be too great to yield any definite concentration. This may account for the greater irregularity of cassiterite occurrences in pegmatite bodies of this sort. Segregations need not always be expected even in the upper parts of sills or low-dipping dikes, since a slight change of conditions, such as faster cooling, might upset the upward migration of the tin compounds. Field observations, however, point to the conclusion that the upward concentration within pegmatite bodies has taken place in a number of cases.

ECONOMIC POSSIBILITIES OF THE TIN DEPOSITS.

If the assumptions that have been made are correct, there would be, for example, very little use in delving deeper into a pegmatite dike containing a few scattered crystals of cassiterite, in the hope of increasing tin values. Even in a rich segregation, values are likely to decrease as the sill or dike is followed down the dip. The difficulty that arises from a practical point of view is that wherever a pegmatite body outcrops, the top, in other words the most favorable part, has probably been at least partially removed. However, where pegmatite bodies that have been struck by diamond drilling or underground working, do not appear to outcrop on the surface, it is reasonable to suppose that whatever tin was concentrated, still remains intact. In the case of a body 200 feet thick or more, the amount of cassiterite segregated might be in economic quantities. Such a concentration would likely be found only by following, as nearly as possible, the roof of the body.

SUMMARY.

1. The magma responsible for the pegmatitic intrusions in the district was stanniferous to some degree.

2. The upper part of the batholith that possibly contained the best part of the tin mineralization has been removed by erosion.

Therefore, typical fissure or replacement veins of cassiterite are not likely to be found at the present level of the surface.

3. The cassiterite was one of the original constituents of the pegmatite.

4. All the cassiterite seen occurs in pegmatite dikes and sills.

5. The same principles involved in tin mineralization on a batholithic scale apply on a small scale in pegmatite bodies, *i.e.* through its association with volatile elements in liquid or gaseous condition, the tin tends to rise to the highest points of the intrusion before crystallizing. This results in segregation occurring at the apices of dome-shaped masses or near the hanging walls of flat-dipping dikes and sills.

6. The upward migration probably took place while the pegmatite was in a viscous state.

7. The most favorable places for segregation of possible economic value are in the roofs of pegmatite bodies not yet exposed by erosion, but which may be picked up by drilling or underground exploration.

ACKNOWLEDGMENTS.

Thanks are due to the officials of the Jack Nutt Mines, Ltd., and the Manitoba Tin Co., for their generous hospitality and assistance in the field.

The writer is also indebted to Professor E. S. Moore, for suggestions and assistance in preparing this paper.

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SEQUENCE OF ORE DEPOSITION IN NORTH IDAHO.[1]

ALFRED L. ANDERSON.

INTRODUCTION.

THE sequence of deposition of the lead-silver ores in north Idaho has been worked out, but little study has been given the copper veins which are widely distributed, mainly for the reason that they have not been as productive as the more valuable lead-silver deposits in their own vicinity. Yet a study of them brings to light some interesting and significant relations which offer additional information on the genesis of the mineral deposits of the entire region and especially on the ore deposits in the well known Coeur d'Alene district.[2] Among these relations may be mentioned the peculiar association of chalcopyrite in the copper veins with ankerite and ferriferous dolomite, an association which is perhaps one of the distinctive features of these deposits, particularly as the lead-silver minerals, which have made the Coeur d'Alene district one of the great lead-silver camps in the world, are associated with siderite. Shannon[3] was first to call attention to this unique relationship of the copper and lead-silver veins and suggested that the veins of the Coeur d'Alene district and the St. Joe River region to the south might be divided into two types—a class of ankerite (including ferriferous dolomite)— chalcopyrite veins, and a class of siderite veins with tetrahedrite and galena. These two classes show some gradational features which indicate a supposed common source from the Idaho batholith.

[1] Published by permission of the Secretary, Idaho Bureau of Mines and Geology. The writer wishes to acknowledge the suggestions of Dr. F. B. Laney of the Department of Geology of the University of Idaho, in the preparation of this manuscript.

[2] Ransome, F. L., and Calkins, F. C., "Geology and Ore Deposits of the Coeur d'Alene District, Idaho," U. S. Geol. Surv., Prof. Paper 62, 1908.

[3] Shannon, E. V., "The Minerals of Idaho," U. S. Nat. Museum Bull. 131, pp. 222-234, 1926.

Probably the preference of each metal, copper and lead, for its own distinctive carbonate gangue might be explained when the paragenesis of each class is considered and related to thermal and structural conditions during deposition. Not all the copper veins are associated with the carbonates, some have quartz alone, but these may correspond to one of the stages recorded in the formation of the more common ankerite-chalcopyrite group.

The genesis of the copper mineralization is the main substance of this article, for heretofore little has been known of these. Most of the details are from work done by the writer in the Clark Fork district [4] which lies about 35 miles north of the Coeur d'Alene district, supplemented by work in the St. Joe and Clearwater river basins south of the Coeur d'Alene district. The work done by Shannon was also freely consulted in the preparation of the article in order to show that these relations do not pertain locally to the Clark Fork district but apply over a wide area. As the paragenesis of the lead-silver ores has been described elsewhere, the writer will use only the general conclusions that have been obtained and show their relation to the broader problem of sequence of ore deposition.

CHARACTER OF THE CARBONATE GANGUE.

The carbonate gangue of the copper veins is invariably a mixed carbonate intermediate between dolomite and ankerite, in which there is probably every gradation from dolomite containing a small amount of iron to ankerite containing relatively little magnesia, most of them consisting of an intermediate mixture containing both iron and magnesia. It is not possible to distinguish between these carbonates except by chemical analysis and as a field name, ankerite might be used to cover all. The variable composition of the copper gangue may be readily seen from the following list of analyses (Table I) from a few veins widely scattered over north Idaho, taken as more or less representative of the entire lot. All but two of the analyses have been made

[4] Anderson, A. L., "Geology and Ore Deposits of the Clark Fork District, Idaho," Idaho Bureau of Mines and Geol., Bull. 12, 1929, in press.

by Shannon [5] from specimens collected in the Coeur d'Alene district and the St. Joe Basin. The others were made by Mr. R. V. Lundquist, Chemist, Idaho Bureau of Mines and Geology, on samples collected by the writer.

TABLE I. ANALYSES OF CARBONATE GANGUES.

Constituents.	Percentages.						
	a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*
$MnCO_3$.....	1.60	2.10	0.66	0.54	0.24	4.38	2.72
$FeCO_3$.....	15.50	19.20	9.96	8.11	10.79	26.81	31.32
$MgCO_3$.....	32.10	23.30	30.80	33.32	28.23	18.29	17.12
$CaCO_3$.....	50.80	55.40	58.58	58.03	60.74	50.52	48.84
Total.....	100.00	100.00	100.00	100.00	100.00	100.00	100.00

a. Ferriferous dolomite, Copper Giant property, Clark Fork district (Lundquist).
b. Ferriferous dolomite, Clearwater Gold and Copper, Clearwater Basin (Lundquist).
c. Ferriferous dolomite, Copper Age claim, Coeur d'Alene district (Shannon).
d. Ferriferous dolomite, Monitor mine, St. Joe Basin (Shannon).
e. Ferriferous dolomite, Manhattan prospect near Monitor (Shannon).
f. Ankerite, Carney copper prospect, St. Joe Basin (Shannon).
g. Ankerite, Reindeer prospect, St. Joe Basin (Shannon).

These carbonates usually show the coarse characteristic rhombohedral cleavage of the group and in color, on fresh fracture, are white to pale buff, or more frequently bluish gray. Less commonly, they occur as small acute and curved rhombohedral crystals lining small vugs in the veins. While it is not possible to differentiate in the field between the magnesian ankerite and ferriferous dolomite, it is possible to separate the members of the dolomite-ankerite series from siderite. They differ from the siderites in their white to grayish color on fresh fracture, whereas the true siderite is always a clean light buff. However, a better distinction is made on the weathered specimens, for the ankerites and ferriferous dolomites become pearly golden brown and the siderites dark brown to black, depending on the manganese content. In the past the carbonates in the copper veins have been erroneously described as siderite, less commonly as dolomite.

[5] Shannon, Earl C., *op. cit.*, pp. 224–227.

ANKERITE-CHALCOPYRITE VEINS OF THE CLARK FORK DISTRICT.

General Relations.

In the Clark Fork district, which lies near the head of Lake Pend Oreille in north Idaho and along the valley of the Clark Fork of the Columbia River, the veins are grouped along the south side of the Hope fault, one of the great earth fractures in the state, similar in every way to the Osburn fault [6] in the Coeur d'Alene district along which most of the mineralization of that district has been centered. They occupy subordinate sets of fractures, which they have in general enlarged by replacement, and range from 12 inches to nine feet wide, of great length, but only mineralized in small uncertain shoots, none of which have been commercially valuable. In the same vicinity are siderite-lead-silver veins also occupying subordinate sets of fissures whose walls have been enlarged by replacement, but these veins unlike the ankerite-copper veins furnish a steady production. The two classes of veins tend to show a zonal arrangement with the copper veins to the west, nearer the batholithic intrusions. All veins are in the Belt series (Algonkian), the siderite-lead-silver veins in the Wallace formation and the ankerite-chalcopyrite class in the Wallace, St. Regis, and Striped Peak. Their location seems to be the result of nearby igneous intrusion and directed along the great fault zone. All veins show readjustments along them concurrent with mineral deposition and probably complementary to the movement along the Hope fault, which was apparently active prior to, during, and after mineralization. This structural feature has an estimated horizontal movement of about 10 miles, and because of an original tilt of the sedimentary beds as a result of earlier folding has caused apparent vertical displacements of as much as 20,000 feet with downthrow on the south.

[6] Umpleby, J. B., "The Osburn Fault, Idaho," *Jour. Geol.*, vol. XXII, pp. 601–614, 1924.

Mineralogy of the Copper Veins.

The mineralogy of the copper veins is comparatively simple consisting in the scattered ore shoots of chalcopyrite, lesser pyrite, in a quartz-ankerite (including ferriferous dolomite) gangue. Several of the veins carry very minor quantities of younger tetrahedrite or galena, and one has magnetite and specularite, older than the other minerals except quartz. The proportions of the minerals vary, the veins in some places being filled essentially with barren quartz, in other places mainly with carbonates, and even locally with chalcopyrite. The chalcopyrite is massive and may be scattered in granules along the vein or may be in compact seams, the largest of which in the Copper Giant vein consists of two to eight inches of solid chalcopyrite for 30 feet along the strike and dip of the vein and the remainder of the shoot, 60 feet long and two feet wide, with scattered grains and masses. The carbonate gangue has the usual features mentioned in an earlier paragraph, and consists of white to grayish granular masses with excellent rhombohedral cleavage, also as curved and acute rhombohedral crystals lining small vugs in the vein. The relation of each of the minerals to the other will be given later.

The history of the deposition is not as simple as the mineralogy would indicate, for in most of the veins there has been movement concurrent with mineral deposition and the fissures have been reopened several times and solutions of different character introduced. Most of the veins show three well-defined stages of deposition, each characterized by a certain group of minerals. Only one vein was seen in which a single stage is represented, and another has as many as five. These abnormal cases will be considered separately.

Stage 1.—The minerals introduced in the first stage of deposition are quartz, pyrite, and chalcopyrite. Practically all the chalcopyrite in the Clark Fork veins was deposited in this earliest stage, which is unlike that in most other parts of north Idaho, where the chalcopyrite was deposited in later stages. These early minerals were deposited mainly as a fissure filling but they show some replacement of the wall rock. The quartz was deposited

first and then after a slight shattering by movement along the vein, which might be considered as a substage, the pyrite was deposited mainly by replacement of the vein quartz, and then lastly the chalcopyrite. Movement along the vein persisted even during the sulphide deposition, for much of the pyrite is shattered and the fractures have been filled as well as enlarged by the chalcopyrite. Perhaps many of the copper veins in the Clearwater Basin and in other parts of north Idaho, which consist of quartz and the two sulphides alone, represent the earliest stage without subsequent reopening and without introduction of younger stage minerals.

Stage 2.—The second stage of deposition was preceded by pronounced movement along the vein which fractured and shattered the early vein filling, reducing it in places to a breccia. The movement was not great, for no parts of the veins are offset more than a few inches, but the shattering was much greater than any that took place during the depositional interval of the first stage. The new solutions that were introduced left a second generation of quartz and the ankerite gangue. The quartz was deposited first and may be seen as veinlets in the shattered chalcopyrite and earlier quartz, but it is much subordinate in quantity to the ankerite and ferriferous dolomite. Some of the quartz fillings in the fractures have an inner seam of the carbonate and some of the quartz which crusts the fragments of ore has an outer coating of the rhombohedral crystals. More commonly, however, the carbonate fills the fractures without any visible evidence of the second generation quartz and it not only fills the fractures in the early vein minerals, but also enlarges them by replacement and in some places has largely replaced the earlier vein filling and has encroached upon the walls. Bands of carbonate an inch to eight inches wide cutting across the vein or along the vein are common. Thus, this stage of mineralization has acted toward impoverishment of the vein by replacing the chalcopyrite ore. In places the carbonate failed to fill all the pre-existing clefts.

Stage 3.—The third stage was preceded by movement along the vein less severe than that which occurred between the first two

stages. The carbonate gangue and, of course, the minerals of the first stage were broken by relatively wide fractures, some of them very minute but some of considerable size, represented now by veinlets of the third stage minerals as much as one-half inch wide. The minerals which were deposited after this third reopening include a third generation quartz accompanied in places by insignificant amounts of chalcopyrite, galena, and tetrahedrite. In some veins only the quartz is represented, in others, one or more of the sulphides. Commonly the quartz occurs in reticulating veinlets cutting the earlier minerals, the chalcopyrite in small grains replacing the carbonate gangue along minute fractures, the galena in the single vein in which it was found as crystals in the open spaces of brecciated quartz and carbonate partially healed by third generation quartz, and the tetrahedrite in fractures in the chalcopyrite and carbonate, also accompanied by a minor amount of quartz. The tetrahedrite in particular tends to show selective replacement of the chalcopyrite. It is probably significant that chalcopyrite again appears in the third stage, although in much smaller quantities than that in the first, especially as the chalcopyrite in the deposits of the Coeur d'Alene district and the St. Joe and Clearwater basins is mainly younger than the ankerite and probably corresponds to the third stage minerals of the Clark Fork deposits. There is a possibility that some of the late quartz veinlets represent even a younger or fourth stage, but the relations are not clear. Evidently the succeeding stages here recorded correspond to weaker and weaker movements along the fissures.

Abnormal Stages—The three stages described above are typical of most of the copper veins including the principal veins in the Copper Giant, Clarinda, and Bumble Bee properties, but does not cover all cases. A notable exception is the Alamo vein, which apparently has but one main stage—early quartz—followed in turn by magnetite, specularite, pyrite, galena and chalcopyrite, and carbonate, accompanied by only slight structural adjustments. This vein serves to tie all stages within one general period of mineralization.

The Carpie vein is another which does not fit, for it shows as many as five stages, three of which correspond to the types mentioned. The earliest stage represented consists of white vein quartz with no other minerals. This filling was then thoroughly brecciated by movement and the resulting breccia was cemented by a siliceous ferric oxide that occurs as a reddish jasper. The vein was again opened a third time, and brecciated only slightly less than it was in the preceding. The new solutions which were introduced deposited a new generation of quartz with pyrite and chalcopyrite, with the same relations as in the first stage of the normal veins. From here on the story is the same. The new filling was fractured, new quartz and ankerite (ferriferous dolomite) introduced to be fractured the fifth time and more quartz and a little chalcopyrite and tetrahedrite deposited. Each reopening was apparently much less severe than the preceding.

Comparison with the Siderite-Lead-Silver Veins.—The lead-silver veins, which occur nearby, show essentially two distinct stages of deposition as in the Coeur d'Alene district,[7] an early filling of siderite which was deposited by replacement of the wall rock as well as by filling of the fissures, and then brecciation by renewed movement along the fissures attended by the circulation of new solutions. In many places the siderite was accompanied by deposition of pyrite, but in places it is barren. The new solutions deposited in turn quartz, pyrite, sphalerite, galena, tetrahedrite, and less commonly a little chalcopyrite. The list is given in the prevailing order of deposition. There was in general some movement concurrent with deposition, for in places the sphalerite shows shattering and then cementation and replacement by both galena and tetrahedrite. The tetrahedrite in turn replaces the galena along cleavage lines. The second stage minerals have been deposited mainly by replacement of the siderite, and it is not unusual to find only residual grains of the siderite left in the sulphides, although every gradation may be found ranging to brecciated siderite only partially healed by quartz and the younger sulphides.

[7] Umpleby, J. B., and Jones, E. L., "Geology and Ore Deposits of Shoshone County, Idaho," U. S. Geol. Survey Bull. 732, p. 135, 1923.

The two stages recorded in the lead-silver veins correspond only loosely to the last two stages of the ankerite-chalcopyrite veins. In general the last stage of both includes nearly the same list of minerals, but in vastly different proportions. Why ankerite should be deposited in the copper veins and siderite in the lead-silver veins is not explained by these relations. As will be pointed out later, it is probable that the copper veins were formed earlier and at higher temperatures than the siderite-lead-silver veins.

ANKERITE-CHALCOPYRITE VEINS IN THE COEUR D'ALENE AND ADJOINING DISTRICTS.

The distribution of the ankerite-chalcopyrite veins in the Coeur d'Alene district and in the adjoining St. Joe River basin has been discussed by Shannon,[8] who finds them more general than the siderite-bearing veins. The writer will not describe the general features of these deposits, except their paragenesis, but will refer the reader to other writers.[9] These veins are especially developed in the upper St. Joe River basin, where the ankerite (originally described as siderite) has associated with it quartz, pyrite, and chalcopyrite, the quartz and sulphides usually in younger veinlets in the carbonate, or the chalcopyrite and pyrite irregularly distributed in grains, seams, and masses of small size. Similar deposits also occur north of the Coeur d'Alene River and are most abundant in the drainage basin of the Little North Fork, where the relations are apparently similar to those in the St. Joe River basin. Recent examinations by Shannon[10] indicate that many of what have been heretofore called siderites in the area of copper prospects east and south of Mullan and also in the numerous prospects in the Prichard formation around Kellogg and on Pine Creek are mixed carbonates intermediate between dolomite and ankerite, and are commonly associated with galena and sphalerite

[8] Shannon, E. V., *op. cit.*, pp. 223–228.

[9] Umpleby, J. B., and Jones, E. T., Jr., *op. cit.*, pp. 109–121; keeping in mind that Shannon has subsequently shown that the gangue mineral is not siderite but ankerite and ferriferous dolomite.

[10] Shannon, E. V., *op. cit.*, pp. 223–228.

as well as iron sulphides (pyrite and pyrrhotite) and chalcopyrite. These deposits with both copper and lead are especially significant because of their bearing on the problem of ore genesis and as a bond between the distinctive lead and distinctive copper types.

Not much attention has been given the problem of mineral relationships in the ankerite-copper veins, but such work as has been done indicates two stages of deposition in which the carbonate is the first. Umpleby and Jones[11] indicate that the priority of siderite (ankerite) to quartz is clearly shown and particularly noticeable along the Bitterroot divide, where quartz veinlets cut siderite (ankerite). In some veins perfect carbonate crystals are partly embedded in quartz that has filled cavities lined with druses of the carbonate. Shannon,[12] in re-examining some of the specimens collected by other workers in the region, finds that in the Manhattan prospect in the St. Joe River basin the carbonate originally lined an open space subsequently filled with quartz; at the Carney, quartz occurs in cracks in the carbonate, and the chalcopyrite appears to replace the carbonate. The ankerite from the Reindeer prospect has later replaced masses of chalcopyrite and a little of a gray sulphide, either tetrahedrite or chalcocite. The same order has been noted by the writer, who visited a few copper prospects in the St. Joe and the Clearwater drainage basins. At the Clearwater Gold and Copper property at the head of the North Fork of the Clearwater the chalcopyrite occurs as massive seams cutting the carbonate and as disseminated crystals replacing the carbonate along minute fractures. It is also accompanied by veinlets of quartz which cut the carbonate. Similar relations have been noted elsewhere. From these relations it is probable that the copper in other deposits as yet unstudied is younger than the ankerite gangue and that deposition has occurred in two well defined stages, an early carbonate deposition and later quartz, pyrite, and chalcopyrite. These should probably be correlated with the second and third stages recorded in the Clark Fork veins. The movement which fractured the

[11] Umpleby, J. B., and Jones, E. L., Jr., *op. cit.*, p. 111.

[12] Shannon, E. V., *op. cit.*, pp. 223–226.

carbonate has apparently, as in the case of the Clark Fork ores, not been severe. Chalcopyrite accompanied by quartz alone also occurs in the Clearwater region, particularly along the Middle Fork near Pardee, but whether these deposits represent a stage corresponding to the first stage in the Clark Fork district or to the second stage in the Coeur d'Alene district (third stage Clark Fork) could not be satisfactorily determined. However, since the veins occur in the batholith they probably belong to the earliest deposition when temperatures were highest and too high for the younger stages.

In the veins in the Pine Creek Basin, where the ankerite has lead and zinc in addition to the pyrite, pyrrhotite, and chalcopyrite, the relations of the sulphides to the carbonate is about the same as in other places. Shannon [13] mentions that the ankerite from the Sherman has cleavage cracks coated with films of pyrrhotite. In a study of the paragenesis of the lead, zinc, and copper sulphides, where these occur in the same deposits, Umpleby and Jones [14] find the primary copper sulphides to be older than galena and possibly younger than sphalerite in places, although as a rule the copper minerals preceded those of zinc. They give the order of deposition as siderite (ankerite), quartz, chalcopyrite, sphalerite, chalcopyrite and tetrahedrite, and galena. The minor accessories, pyrite and pyrrhotite (locally predominating), come between the quartz and chalcopyrite. As in the more typical ankerite-chalcopyrite veins the quartz and sulphides were introduced after the early carbonate was fractured.

The siderite-galena-silver veins in the Coeur d'Alene district show essentially two stages, early siderite, deposited and fractured before the quartz, sphalerite, and galena were introduced.[15] An additional third stage is recorded in the Pend Oreille district,[16] where chalcopyrite, polybasite, and proustite coat and fill cracks in the earlier fillings, but this has been of variable importance.

[13] Shannon, E. V., *op. cit.*, p. 228.

[14] Umpleby, J. B., and Jones, E. L., Jr., *op. cit.*, p. 120.

[15] Umpleby, J. B., and Jones, E. L., Jr., *op. cit.*, p. 135.

[16] Sampson, Edward, "Geology and Silver Ore Deposits of the Pend Oreille District, Idaho," Idaho Bur. Mines and Geol. Pamphlet No. 31, pp. 20–21, 1928.

GENETIC RELATION OF THE ANKERITE AND SIDERITE ORES.

In the Clark Fork district, the writer believes the copper veins and lead-silver veins were deposited during one general period of mineralization and are genetically related. Umpleby and Jones [17] also conclude that the deposition of minerals in the Coeur d'Alene district and the whole of Shoshone County, which includes the St. Joe Basin, was within one general period of mineralization, interrupted by structural disturbance so that different lodes were reopened at different times. They account for the difference in the copper and lead veins on the basis of regional variation in composition of the mineral-depositing solutions as a result of which the siderite (ankerite)-chalcopyrite deposits are localized in two general areas apart from large lead and zinc deposits. Doubtless regional variation in composition of the solutions in part explains these relations, but the writer believes the fundamental cause to go even farther, and that the composition is due to other factors, notably the temperatures at which deposition occurred.

Genetic Classification of the Ankerite and Siderite Veins.

Lindgren [18] describes the siderite-galena veins in the Coeur d'Alene district as examples of mesothermal deposits, formed at intermediate temperatures by ascending thermal waters and in genetic connection with intrusive rocks. Studies of the copper veins on the other hand tend to show that the temperatures of the earlier solutions were higher and more nearly hypothermal. Evidence of this in the Clark Fork district is afforded by the occurrence of magnetite and specularite in one of the veins, and of ferric oxide as jasper in another, minerals more common to hypothermal deposits. None of these minerals have been found in the siderite-lead veins. Elsewhere, the writer [19] has explained that the copper veins were probably formed earlier than the siderite-lead veins and that the latest reopening permitted some of the

[17] Umpleby, J. B., and Jones, E. L., Jr., *op. cit.*, pp. 132–134.

[18] Lindgren, Waldemar, "Mineral Deposits," Third Ed., pp. 646–650. McGraw-Hill Book Co., 1928.

[19] Anderson, A. L., *op. cit.*, in press.

younger solutions to deposit minor amounts of galena. Evidence of earlier deposition and higher temperatures is also afforded in the Coeur d'Alene district, where Umpleby and Jones [20] consider the copper deposits to represent an early phase of the zinc-lead deposition. The studies of the paragenesis show that the chalcopyrite is mainly older than the sphalerite and galena, but the relative age of the copper and lead-zinc deposits is best determined by a study of the veins themselves. They explain the distribution of the veins in a broad zone parallel to great west-northwest faults, notably the Osborn and Placer Creek faults, and that the ore deposits were formed concurrently with movements in the fault (Osburn), probably distributed through a long period of time. The quartz-siderite (ankerite) veins are given as simple fissures opened during early stages of this faulting movement and filled with siderite (ankerite), quartz, pyrite, and chalcopyrite. These are cited as occurring outside the zone affected by later movements and adjustments along the Osburn fault and possibly for that reason were not penetrated by the later zinc and lead solutions.

The higher temperatures of deposition are also indicated by the presence of pyrrhotite in many of the veins and this is particularly true of the ankerite-chalcopyrite veins along the South Fork of the Coeur d'Alene River. The distribution of the deposits also offers additional evidence, for the ankerite-chalcopyrite veins in the St. Joe and Clearwater basins are in areas that show notable igneous metamorphism, quite in contrast with the usual occurrence of the siderite-lead veins in regions of only slight metamorphism. Hence, the copper veins occur well toward the margin of the main Idaho batholith in the Clearwater Mountains whereas the siderite-lead veins remain far back. It is especially noteworthy that where ankerite occurs with both copper and lead (and zinc) in the Pine Creek Basin, it is accompanied by pyrrhotite which offers decisive evidence of high temperatures or hypothermal conditions during deposition.

[20] Umpleby, J. B., and Jones, E. L., Jr., *op. cit.*, p. 120.

Temperature and Its Relation to Deposition of Ankerite and Siderite.

The relations discussed in the preceding paragraph indicate that the copper deposits were formed earlier and at higher temperatures than the siderite-bearing veins. Perhaps, therefore, the ferriferous dolomites and ankerites are the more stable minerals at higher temperatures and the siderite at somewhat lower; or, stated in another way, the magnesium-calcium carbonate proved more insoluble than the iron carbonate at higher temperatures, and as precipitation advanced the iron continued to concentrate, replacing more and more of the magnesium to form ankerite, and, in the final stages, took the place of the lime to form siderite. It is probable that the chalcopyrite was deposited during the earlier interval when temperatures were higher and the solutions were richer in lime and magnesia and that the lead and zinc were later precipitated at lower temperatures within the range of the siderite or slightly later, readjustments along the fissures at the proper time, which permitted the solutions of different composition to be introduced, accounting for the two main classes of veins. It has been explained that chalcopyrite in the Clark Fork ores was deposited before the ankerite or ferriferous dolomite as well as after, and it is obvious that the history of any vein is complex. Overlapping of the two main kinds of deposits should be expected. The presence of minor amounts of galena and tetrahedrite give evidence of this, and the best example, perhaps, is the occurrence of the galena and sphalerite in the chalcopyrite-ankerite veins in the Pine Creek Basin, which are further characterized by the presence of pyrrhotite. These deposits tend to show the gradation of the two main classes where structural readjustments, perhaps, failed at the proper time, and may offer proof of the dominance of ankerite over siderite at the higher temperatures. This brings up the interesting speculation of whether the lead-silver deposits in the Coeur d'Alene district which have given way to pyrrhotite in depth [21] might not show a corresponding change from siderite to ankerite or ferriferous dolomite. If

[21] Ransome, F. L., and Calkins, F. C., *op. cit.*, p. 178.

studies should show this, the theorem here presented would be proven and one might even go so far as to say that perhaps the copper veins in the St. Joe and Clearwater basins might represent the roots of former lead-silver veins, planed away by erosion.

SUMMARY AND CONCLUSIONS.

A study of the mineralization in north Idaho shows that the copper veins are unique in that the chalcopyrite is invariably accompanied by an ankerite or ferriferous dolomite gangue in contrast with the valuable lead-silver veins which have a usual siderite gangue. These two classes of veins are related genetically and probably owe their distribution to differences in thermal conditions and structural readjustments along fissures during deposition—the copper being deposited earlier and at higher temperatures than the lead and silver, and deposited during the interval in which the more insoluble dolomite and ankerite were precipitated. On the other hand, the lead, zinc, and silver remained in solution longer and were concentrated along with the iron to be later precipitated as sulphides in association with a siderite gangue.

The formation of the copper veins has not in general been a simple process, but deposition has proceeded in places in three well defined stages, corresponding to as many reopenings of the vein or fissure. In the Clark Fork district, the first stage is represented by the deposition of quartz, pyrite and chalcopyrite, the second stage by quartz, ankerite, or ferriferous dolomite, and the third stage by quartz, chalcopyrite, and minor amounts of galena and tetrahedrite. In the Coeur d'Alene district and the St. Joe and Clearwater river basins to the south, the deposition has been in two fairly distinct stages, an early ankerite or ferriferous dolomite stage followed in turn by quartz and chalcopyrite, stages which correspond to the final two in the Clark Fork district. The carbonate and final chalcopyrite stage are closely bound together, but a considerable break exists between the early copper and the later carbonate. Many quartz-chalcopyrite veins occur in the region and these possibly represent the earliest stage, as recorded in the Clark Fork district, subsequently reopened

and further mineralized. Indeed, the Clark Fork veins may be unique in showing all stages. The formation of the younger lead-silver veins has been less complex and has involved essentially only two stages, early siderite, deposited and fractured before the quartz, sphalerite, and galena were introduced.

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THE GOLD RESOURCES OF ALASKA.[1]

PHILIP S. SMITH.

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HISTORY AND PRODUCTION.

GOLD has been won in varying quantities from mines distributed from almost one extremity to the other of the Territory and from both lodes and placers. The earliest authenticated recognition of gold in the Territory was during the Russian occupation of the country. As early as 1848 Doroshin reported finding gold in the gravels of Kenai River, and in 1850 and 1851 he made efforts to discover a deposit of commercial value in that region, though without success.[2] In 1865–1866 parties serving under von Bendeleben are said to have recognized placer gold in Seward Peninsula,[3] though the finds apparently were not regarded as of economic importance. In the early seventies, according to Prindle,[4] gold was recognized in the Yukon-Tanana region of central interior Alaska. It was 1880, however, before any considerable amount of gold was actually produced from the Territory. This was recovered from placers in the Juneau region and amounted to about $6,000. Productive lode mining in the

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Martin, G. C., and others, "Geology and Mineral Resources of Kenai Peninsula, Alaska," U. S. Geol. Survey Bull. 587, pp. 181–182, 1915.

[3] Collier, A. J., and others, "Gold Placers of Parts of Seward Peninsula," U. S. Geol. Survey Bull. 328, p. 13, 1908.

[4] Prindle, L. M., and others, "Geologic Reconnaissance of the Fairbanks Quadrangle, Alaska," U. S. Geol. Survey Bull. 525, p. 13, 1913.

TABLE I.

VALUE OF GOLD PRODUCED IN ALASKA, 1880–1929, BY SOURCES.

Year.	Placer Mines.	Lode Mines.	Total.
1880	$ 6,000	.....	$ 6,000
1881	15,000	.....	15,000
1882	20,000	$ 3,000	23,000
1883	51,000	5,000	56,000
1884	51,000	21,000	72,000
1885	125,000	300,000	425,000
1886	150,000	390,000	540,000
1887	130,000	527,000	657,000
1888	135,000	530,000	665,000
1889	140,000	700,000	840,000
1890	150,000	680,000	830,000
1891	220,000	780,000	1,000,000
1892	240,000	765,000	1,005,000
1893	250,000	840,000	1,090,000
1894	450,000	870,000	1,320,000
1895	809,000	1,725,000	2,534,000
1896	960,000	1,820,000	2,780,000
1897	665,000	1,770,000	2,435,000
1898	645,000	1,600,000	2,245,000
1899	3,480,000	1,835,000	5,315,000
1900	5,623,000	2,272,000	7,895,000
1901	4,980,000	2,220,000	7,200,000
1902	5,887,000	2,448,000	8,335,000
1903	6,010,000	2,738,000	8,748,000
1904	6,025,000	3,090,000	9,115,000
1905	12,340,000	3,506,000	15,846,000
1906	18,607,000	3,429,794	22,036,794
1907	16,491,000	2,858,743	19,349,743
1908	15,888,000	3,404,818	19,292,818
1909	16,252,638	4,159,078	20,411,716
1910	11,984,806	4,141,943	16,126,749
1911	12,540,000	4,313,256	16,853,256
1912	11,990,000	5,155,951	17,145,951
1913	10,680,000	4,946,813	15,626,813
1914	10,730,000	5,034,259	15,764,259
1915	10,480,000	6,222,144	16,702,144
1916	11,140,000	6,101,713	17,241,713
1917	9,810,000	4,847,353	14,657,353
1918	5,900,000	3,580,952	9,480,952
1919	4,970,000	4,456,032	9,426,032
1920	3,873,000	4,492,560	8,365,560
1921	4,226,000	3,847,540	8,073,540
1922	4,395,000	3,027,367	7,422,367
1923	3,608,500	2,376,814	5,985,314
1924	3,564,000	2,721,724	6,285,724
1925	3,223,000	3,137,281	6,360,281
1926	3,769,000	2,938,000	6,707,000
1927	2,982,000	2,945,000	5,927,000
1928	3,347,000	3,498,000	6,845,000
1929 (estimated)	3,992,000	3,766,000	7,748,000
Total	$254,000,000	$126,838,000	$380,838,000

Territory also appears to have started in the vicinity of Juneau in 1882, though as early as 1871 attempts had been made to mine lodes in the vicinity of Sitka. It was, however, not until 1885 that the yield from the gold lodes near Juneau amounted to more than a few thousand dollars annually. The record of the production of gold from Alaska lode and placer mines since that time is given in Table I.

This record of production is also graphically shown by Figure 1. From this figure can be traced the rather gradual growth of

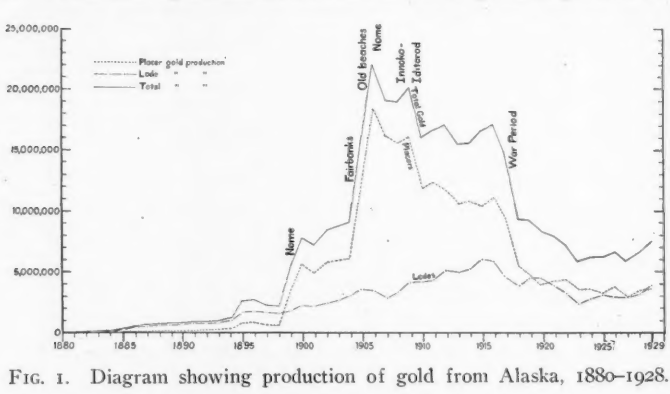

FIG. 1. Diagram showing production of gold from Alaska, 1880–1928.

the lode gold industry to a peak in 1915 of $6,222,000, and then the sudden decline in 1917, due to the World War, together with a disaster which resulted in permanently closing down the largest lode mine then operating in the Juneau district. Since that time the lode production has remained rather constantly between three million and four million dollars a year.

In this same figure may also be traced the sudden rise of the placer production from 1895 and 1896, when the placers of the camps in the eastern part of the Yukon basin near the international boundary first began to yield much gold, through the sudden great increase brought about by the discovery of productive placers at Nome in 1899–1900 and at other parts of the Territory as the gold seekers, lured north by the phenomenal finds in the

Klondike region, began to spread out through other parts of the northland. Then followed the discovery of some of the rich camps of interior Alaska, notably Fairbanks in 1903, Iditarod and Innoko in 1908–1909, and Ruby in 1910–1911, together with many less spectacular camps, so that from 1905 to 1916, inclusive, the annual production of placer gold was more than $11,000,000, and in 1906 reached a peak of over $18,000,000. The outbreak of the World War and the participation in it by the United States caused a great decline in placer production from Alaska, a condition that has continued to the present, with a placer production of approximately $3,000,000 to $4,000,000 a year.

PLACERS.

General Features.—It is impracticable within a short space to describe in detail the many camps where placer gold has been produced in Alaska. All the known camps have been visited by geologists of the U. S. Geological Survey, as well as by many others, and hundreds of reports have been prepared by them, describing their findings. In order, however, to present within a small space the most pertinent facts regarding the larger regions or districts, the accompanying Table II and diagram (Fig. 2) have been prepared, with the collaboration of Messrs. S. R. Capps, F. H. Moffit, and J. B. Mertie, Jr. To understand this table and figure it should be realized that the many mines and prospects have been grouped into some 52 districts, though there are many individual properties that lie far outside the spots used on the map to indicate the different main tracts. For instance, in Seward Peninsula there is hardly a valley of any size from which some placer gold has not been taken. Furthermore, many parts of Alaska are still so inaccessible that they have been little investigated, even by prospectors, and more than half the Territory has not been surveyed either topographically or geologically by the Government, so that the map records past performance rather than indicating all the potential placer areas.

Many different classifications of placer deposits have been proposed and used. For the sake of simplicity, however, in this

FIG. 2. Map of Alaska showing distribution of areas in which gold placers have been developed. Numbers refer to districts described in more detail in Table II, pp. 189–192.

article only the broadest subdivision into beach and stream placers has been given. There are no districts in which the principal type of placer is either residual or glacial, although examples of these types, which have been modified by streams, are recognized, in several of the districts. An attempt to subdivide further the stream placers into those of the present streams and bench or buried deposits of ancient streams proved ineffective because both types are represented in practically all the larger producing districts. In fact, most of the bonanzas have been produced by reconcentrations effected through more than one period of sorting.

Condensation of the description of the geologic setting of the placers of the different districts has necessarily resulted in tabulating only a few of the more significant facts and the omission of many of the structural, dynamic, physiographic, and intrusional episodes which doubtless were contributory causes of the accumulation of placers at the specific places where they occur.

In designating the principal methods of mining in use at the different camps only the most general subdivisions have been made, and decision as to which is the principal type has been based on the records regarding the amount of production recently yielded by the different methods. Thus, the description of the Nome-Bluff placers as being mined principally by dredging and varied mechanical plants does not preclude the fact that there are still many small outfits using mainly manual methods or that in the past much of the gold was won by manual hydraulic and underground methods. On the whole, the term *manual* as applied to mining methods is here used to designate those simpler plants in which the work is done mainly by man power, shoveling into sluice boxes or similar contrivances. In the category of mechanical methods are those using hydraulic elevators, dragline scrapers, power shovels, and similar devices. Dredging and hydraulic methods are clearly indicated by their names. The underground methods have been developed as a more or less unique response to the permanently frozen condition of certain of the placers. By this method a relatively thin layer of rich gold-bearing gravel is dug out separately, without removing barren layers

FIG. 2. Map of Alaska showing distribution of areas in which gold placers have been developed. Numbers refer to districts described in more detail in Table II, pp. 189–192.

of sand and gravel, by means of shafts sunk to the auriferous layer and then drifting along it and hoisting the pay gravels to the surface, where they are sluiced to recover the gold that they contain. A comprehensive report that describes in much detail the various mining methods used in Alaska has recently been prepared by Wimmler.[5] With the development of Alaska the present tendency is to operate larger units and to use more extensively power and machines for mining. As a result, although there are doubtless many places still remaining where persons with small capital and little equipment may find profitable placers, most of the easily won fabulously rich bonanzas have been found, and the best opportunities for success now await enterprises directed by well qualified experts and backed with ample funds. Alaska is still a land of promise, as is evidenced by the large-scale operations recently put into effect in the Nome and Fairbanks districts.

The designation of the value of the production of the various camps by the terms large, medium, and small, rather than by specific numerical quantities, has been adopted to avoid gaps where the information necessary for a more precise statement is not available and to avoid disclosure of the production of individuals in many of the smaller camps. Although the terms used have not been given any precise numerical value, it may be helpful to the reader to learn that an approximate scale which served as a guide in making these distinctions was that a very large production from a single district is considered to be more than $10,000,000 and that a small production is something less than $500,000. The total production of placer gold from Alaska mines to the close of 1928 was $250,008,000, of which amount over $90,000,000 came from camps on Seward Peninsula and over $75,000,000 from the placers of the Fairbanks district.

In the last column of Table II is given a reference to the Survey publication which furnishes the most comprehensive description of the individual district. The reference is not always to the latest available report; in fact, late developments or current statistical facts regarding the deposits are to be sought in the

[5] Wimmler, N. L., "Placer Mining Methods and Costs in Alaska," U. S. Bureau of Mines Bull. 259, 236 pp., 1927.

series of Alaskan bulletins, one of which is published each year by the Geological Survey and covers the preceding calendar year. A complete catalogue of all Geological publications relating to Alaska, most of which contain descriptions of gold deposits, is contained in the Survey's general "List of Publications" and a selected list arranged by districts forms part of each annual volume.[6]

Reserves.—Those most familiar with the mineral resources of Alaska recognize that quantitative data regarding much of the Territory is so inadequate that estimates of placer reserves at this time can be little better than surmises. That the reserves are large can not be doubted; that, judging from the facts in hand, the reserves may be $500,000,000, or twice as great as the amount of placer gold already recovered, seems reasonable; that new large-scale developments may demonstrate reserves of even more than double the past production is regarded as not at all improbable. Brooks, who in 1919 attempted to determine the amount of placer gold reserves, stated; "In view of the above facts, it is believed that the available placer gold reserves in the developed districts of Alaska have a value of at least $360,000,000 and perhaps of twice that amount. There is also the possibility of discoveries of new deposits, of which not even a rough estimate can be made."[7] In the ten years since that estimate was made by Brooks many developments have taken place which tend to increase rather than decrease the estimates made by him of the potential reserves. The completion of the Alaska Railroad, the building of automobile roads through many parts of the Territory, and the commercial use of airplanes have greatly facilitated transportation and many phases of placer development. This can be demonstrated by the following facts. In the ten-year period preceding and including 1919 the average value of the gold recovered per cubic yard of gravel mined was nearly $1.59. In

[6] Recent volumes of this series are as follows: For 1925, U. S. Geol. Survey Bull. 792; for 1926, U. S. Geol. Survey Bull. 797; for 1927; U. S. Geol. Survey Bull. 810; for 1928, U. S. Geol. Surv. Bull. 813.

[7] Brooks, A. H., "The Future of Alaska Mining," U. S. Geol. Surv. Bull. 714, p. 11, 1921.

the four-year period following 1919 and including the years 1920 to 1923 the average value of the gold recovered per cubic yard of gravel was 82.7 cents or only a little more than half that in the earlier period. In other words, the miners were then working placers of much lower tenor than when Brooks' estimate was made. Even further reduction is to be expected, as well equipped plants operating efficiently on large units are installed. Further corroboration of this belief is furnished by the records available from dredging operations. In 1919 the small dredges then in operation handled approximately 1,760,000 cubic yards of gravel which yielded on the average about 77 cents in gold a cubic yard, whereas in 1927 dredges handled more than 6,080,000 cubic yards of gravel and recovered an average of about 28.6 cents a cubic yard. The foregoing figures as stated are records of recovery and are in no sense operating costs or net returns and therefore should not be interpreted as directly showing increased efficiency of mining methods or impoverishment of rich deposits. They do, however, clearly reflect the fact that gravels containing gold worth less than 30 cents a cubic yard, or less than forty per cent. of the value that was current at the time Brooks made his estimate of reserves, are now being successfully mined in Alaska.

In Table II, which gives the principal features of the different placer districts, a column has been devoted to setting forth the probable reserves of each district. The terms large, small, and medium used in that column have not been given any specific numerical value, but on the whole, it may be said that the reserves of those districts, which probably contain less than $5,000,000 in placer gold are regarded as small, whereas those which are believed to contain more than $25,000,000 in placer gold are considered large.

LODES.

General Features.—As has been stated, lode mines in Alaska have yielded up to the close of 1928 gold valued at more than $123,000,000, or about half as much as has been won from Alaskan placers. At present the annual output is at the rate

of between $3,000,000 and $4,000,000 but for the years 1912 to 1916 inclusive, it was $5,000,000 to $6,000,000 or more. Although the amount of lode gold produced in 1928 was less than was produced in the years immediately preceding the entrance of the United States into the world war, it was more than had been produced in any of the six years from 1922 to 1927, inclusive. Therefore, instead of the recent production from the lode mines marking a point on a curve of declining production, it really falls on a curve having an upward trend and records the partial recovery of the production from the effects of the war. In other words, there is no basis from the facts available to believe that the peak of Alaskan lode production has yet been reached.

Lodes carrying gold are widely distributed through the Territory, and an attempt has been made to show in Fig. 3 the districts that have yielded most lode gold. The figure, however, is by no means adequate to show the wide extent of gold mineralization, for far outside the area of the producing districts veins are known that, if more accessible or of higher tenor, would well warrant more intensive investigation. In fact, it may be said with a good deal of confidence that as yet the gold lode resources of Alaska as a whole are practically unexploited. With the exception of a very few mines, all the lode gold developments have been undertaken by small inadequately financed companies, without skilled technical or administrative advice, operating on such a small scale that costs were inordinately high. In contrast with these small projects which with difficulty, if at all, have managed to carry on their work, may be cited the large mine of the Alaska Juneau Gold Mining Co., which in 1927 mined at a profit more than 4,267,800 tons of ore from which the total value of the metal recovered was somewhat less than 58 cents a ton. This mine is advantageously situated for cheap transportation and reasonably easy accessibility in Southeastern Alaska, so that its costs are necessarily far below those that would obtain in more remote districts. They are, however, in startling contrast to the present practice in some of the mines elsewhere as, for instance,

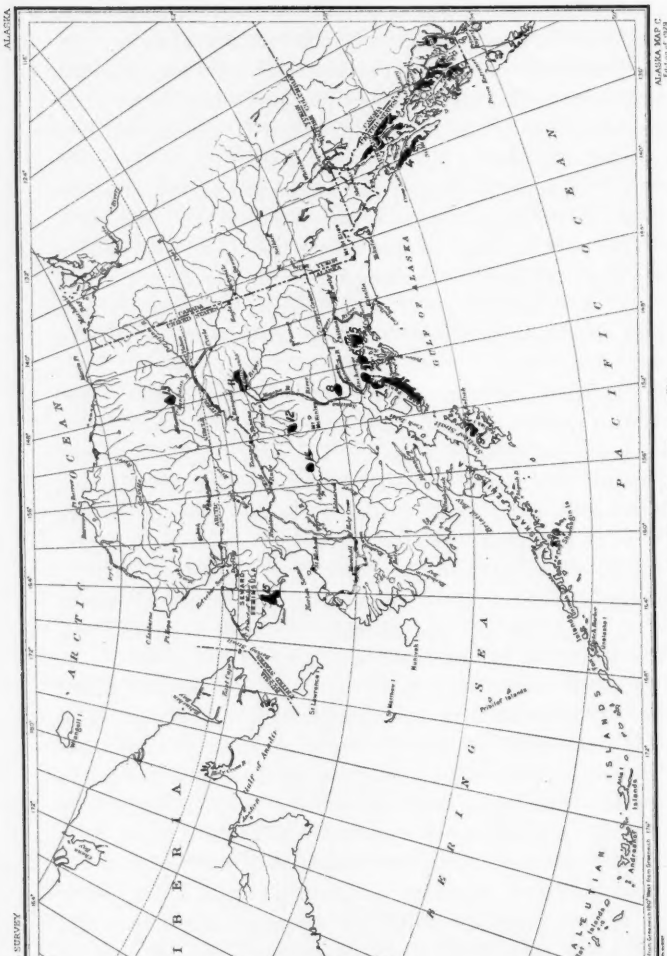

FIG. 3. Map of Alaska showing distribution of areas in which gold lodes have been developed. Numbers refer to districts described in more detail in Table III, pp. 193–196.

near Fairbanks, where losses in gold up to several dollars a ton are admitted by some of the mill operators, or other mines, such as those in the Kantishna, where $100 ore barely pays the costs of its transportation to outside smelters for treatment.

Some indication of the probable wide distribution of gold lode mineralization is afforded by the distribution of the gold placers. Although some of the placers have probably been derived from disseminated mineralization of too low grade to be mined as lodes, many unquestionably have been formed by the concentration of gold from more localized veins and lodes. There is therefore every reason to believe that as the Territory becomes more opened up and costs are lowered, some of these may be mined successfully. Prospecting, however, is difficult in most parts of Alaska because of the thick mantle of moss and vegetation, the relatively short open season in the interior, the generally higher costs than in the States, the absence of population, and the outlay required in developing lodes, which is much greater than in developing placers. These, however, are conditions that are not insuperable or permanent, and as the number of successful enterprises increases, these present handicaps will become less and less determinative.

In order to present in a condensed form the most significant facts regarding the different lode districts, the information has been arranged in tabular form. It will be noted from the descriptions of the principal geologic features that most of the lode districts include or are in close proximity to tracts of intrusive igneous rocks mainly of granitic composition. Intrusives of this sort are widely distributed throughout Alaska from the Brooks Range southward to the furthermost limits of the Territory. Placers have been found near the margins of many of these intrusive masses, and in some places, notably in Southeastern Alaska, extensive lode mineralization has been found and partly developed.

Reserves.—The facts necessary for making specific determinations of the lode gold reserves of Alaska are not available. None of the camps have yet been prospected thoroughly enough to

FIG. 3. Map of Alaska showing distribution of areas in which gold lodes have been developed. Numbers refer to districts described in more detail in Table III, pp. 193–196.

block out the ore either laterally or vertically from the unprofitable country rock. General development is beginning to make available places that formerly were unknown or practically unreachable. Successful operation of some of the larger properties is affording details regarding the mode of occurrence of the ore and other significant geologic features as well as yielding actual figures on mining and other costs that will encourage operators to enter the field with a sound groundwork of facts on which to base judgment and with assurance that there are large tracts of mineralization, some of which will doubtless well repay outlay of capital and effort. In Southeastern Alaska alone lode gold worth nearly $100,000,000 has been produced from ores most of which carried only $2 to $3 a ton in gold and some of which carried less than $1 a ton. That there are very large reserves of ore of this low tenor seems certain. Doubtless in many parts of the Territory, because of the more complex character of the mining and milling treatment or their greater remoteness, ores to be profitable must contain much more than that amount of gold. Although it is unjustifiable at this time to give any precise estimate of the lode gold reserves in the different districts, it is the general feeling of those geologists of the Geological Survey who are most familiar with the existing mines that the probable reserves are very large, and that those of the different major divisions probably stand in somewhat the following order from largest to smallest: Southeastern Alaska, central southern Alaska, Yukon Valley, southwestern Alaska. Developments in northwestern Alaska and the Kuskokwim valley are too meager to warrant placing these regions in the foregoing list. Perhaps the most definite statement that is warranted regarding the gold lode reserves of Alaska is that made by Brooks,[8] who said, "It is quite possible that the reserve of lode gold far exceeds that of the placers."

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

[8] Brooks, A. H., "The Future of Alaska Mining," U. S. Geol. Surv. Bull. 714, p. 12, 1921.

TABLE 11

SUMMARY OF PRINCIPAL PLACER REGIONS AND DISTRICTS OF ALASKA.

TABLE 11

SUMMARY OF PRINCIPAL PLACER REGIONS AND DISTRICTS OF ALASKA.

Reference No.	Name of District or Principal Camp.	Character of Country Rock. Lithology, Age, Structure and Relation to Source of Mineralization.	Principal Method of Mining at Present in Use.	Past Production.	Probable Reserves.	Reference U.S.G.S. Bull.
	SOUTHEASTERN ALASKA:					
1.	Juneau	Metamorphic rocks dominantly of Mesozoic age intruded by large masses of Mesozoic granitic rocks with numerous quartz veins.	Simple manual	S[1]	S[1]	287
2.	Porcupine	Metamorphic slates, limestones and phyllites of Carboniferous (?) age intruded by masses of Mesozoic granitic rocks with numerous quartz stringers.	Manual; hydraulic	M	M	699
	CENTRAL SOUTHERN ALASKA:					
3.	Lituya	Nearest consolidated rocks sandstones, shales, and conglomerate of Pliocene (?) age.	Simple manual	S	S	662
4.	Yakataga	Nearest consolidated rocks tilted Tertiary sediments.	Simple manual	S	S	592
	COPPER RIVER:					
5.	Nizina	Mesozoic slates, porphyry intrusions, quartz stringers.	Hydraulic	L	M	448
6.	Chisna-Slate Creek	Probably Paleozoic slates.	Hydraulic	L	M	498
7.	Bremner	Probably Mesozoic slates and graywackes, porphyry intrusions, quartz stringers.	Hydraulic	S	S	576
8.	Nelchina	Mesozoic slates.	Manual	S	S	668
	PRINCE WILLIAM SOUND—SUSITNA:					
9.	Kenai Peninsula (Northern)	Mesozoic slates and graywackes, porphyry intrusions, quartz stringers.	Hydraulic	L	L	587
10.	Kachemak Bay	Tertiary sediments.	Manual	S	S	277

[1] S, small; M, medium; L, large.

TABLE II—*Continued.*

Reference No.	Name of District or Principal Camp.	Character of Country Rock. Lithology, Age, Structure and Relation to Source of Mineralization.	Principal Method of Mining at Present in Use.	Past Production.	Probable Reserves.	Reference U.S.G.S. Bull.
11.	Willow Creek	Early Paleozoic or older schist and Mesozoic granite, quartz veins.	Hydraulic	S	S	607
12.	Yentna-Fairview	Mesozoic, slate and graywacke, and Eocene sediments.	Hydraulic; dredge	M	S	534
13.	Valdez Creek	Mesozoic, arkoses, limestone, tuff, in part metamorphosed.	Hydraulic	S	S	498
14.	Uyak-Uganik	Glacial till and outwash. Mesozoic slate and graywacke	Manual	S	S	692
15.	Southwestern Kodiak	Glacial till and outwash. Mesozoic slate and graywacke.	Manual	S	S	692
	YUKON BASIN:					
16.	Chisana (Shushanna)	Mesozoic slate and graywacke.	Manual	S	S	630
17.	Bonnifield	Early Paleozoic or older schist, metamorphosed Paleozoic schist, Eocene sediments.	Hydraulic	M	S	501
18.	Kantishna	Early Paleozoic or older schist, granitic intrusives.	Hydraulic	M	M	687
19.	Fortymile	Early Paleozoic or older schist, granitic intrusives.	Manual, mechanical, hydraulic, underground	L	L	375
20.	Seventymile–Eagle	Early Paleozoic or older schist, granitic intrusives	Manual, hydraulic	M	M	538
21.	Woodchopper–4th of July	Paleozoic, Mesozoic and Tertiary sediments, Mesozoic granitic rocks.	Manual, hydraulic	M	M	538
22.	Circle	Early Paleozoic or older schist, Mesozoic granitic intrusives.	Manual, hydraulic, dredge, underground	L	L	538
23.	Chena-Salcha	Early Paleozoic or older schist, Mesozoic granitic intrusives.	Manual	S	S	525
24.	Richardson-Tenderfoot	Early Paleozoic or older schist, Mesozoic granitic intrusives.	Manual, underground	L	S	525
25.	Fairbanks	Early Paleozoic or older rocks, Mesozoic granitic intrusives.	Mechanical, hydraulic, dredging, underground	L+	L	525

TABLE II—*Continued.*

24.	Richardson-Tenderfoot	Early Paleozoic or older schist, Mesozoic granitic intrusives.	Manual, underground	L	S	525
25.	Fairbanks	Early Paleozoic or older rocks, Mesozoic granitic intrusives.	Mechanical, hydraulic, dredging, underground	L+	L	525

TABLE II—*Continued.*

Reference No.	Name of District or Principal Camp.	Character of Country Rock. Lithology, Age, Structure and Relation to Source of Mineralization.	Principal Method of Mining at Present in Use.	Past Production.	Probable Reserves.	Reference U.S.G.S. Bull.
26.	Tolovana-Livengood	Paleozoic sediments, Mesozoic and Tertiary granitic trusives.	Hydraulic, underground	L	M	662
27.	Hot Springs-Rampart	Paleozoic and Mesozoic sediments, Mesozoic and Tertiary granitic intrusives.	Hydraulic, underground, dredge	L	L	535
28.	Gold Hill	Paleozoic sediments, Mesozoic or Tertiary granitic intrusives.	Underground	M	S	520
29.	Dall River	Paleozoic and older sediments, Mesozoic granite.	Manual	S	S	631
30.	Hodzana River	Early Paleozoic or older schist, Mesozoic granodiorite.	Manual, underground	S	S	532
31.	Chandalar	Paleozoic sediments, Mesozoic granitic intrusives.	Hydraulic, underground	M	M	773
32.	Upper Koyukuk	Paleozoic and pre-Cambrian rocks, Mesozoic granitic intrusives.	Manual, mechanical, hydraulic, underground	L	L	532
33.	Hughes-Red Mountain	Mesozoic seciments, Tertiary granitic intrusives.	Manual	S	S	631
34.	Ruby-Poorman	Paleozoic and older rocks, Mesozoic granitic rocks.	Hydraulic, mechanical, dredging, underground	L	L	754
35.	Cripple Creek	Mesozoic sediments, and Tertiary granitic intrusives.	Manual	S	S	578 754
36.	Innoko-Tolstoi-Takotna	Mesozoic sediments, and Tertiary granitic intrusives.	Hydraulic, mechanical, dredge, underground	L	L	578, 754
37.	Iditarod	Mesozoic sediments, and Tertiary granitic intrusives.	Hydraulic, mechanical, dredge	L+	M	754
38.	Marshall	Mesozoic sediments, Paleozoic greenstone, Tertiary granitic rocks.	Manual, mechanical, hydraulic	L	M	683
	KUSKOKWIM RIVER:					
39.	Medfra	Paleozoic and Mesozoic sediments, Tertiary granitic rocks.	Manual	S	S	783
	McGrath	Included in Innoko-Tolstoi-Takotna, No. 36.				

TABLE II—*Continued.*

Reference No.	Name of District or Principal Camp.	Character of Country Rock. Lithology, Age, Structure and Relation to Source of Mineralization.	Principal Method of Mining at Present in Use.	Past Production.	Probable Reserves.	Reference U.S.G.S. Bull.
40.	Georgetown	Mesozoic sediments, and Tertiary granitic intrusives.	Manual	S	S	655
41.	Oknagamut	Paleozoic and Mesozoic sediments, granitic intrusives.	Manual	S	S	622
42.	Aniak-Tuluksak	Paleozoic and Mesozoic sediments, granitic intrusives.	Dredge, manual	S	M	622
43.	Kiselalik-Kanektok	Paleozoic and Mesozoic sediments, granitic intrusives.	Manual	S	S	622
44.	Goodnews-Arolik	Paleozoic and Mesozoic sediments, Tertiary and Mesozoic granite rocks.	Mechanical and manual	S	S(?)	714
	SEWARD PENINSULA:					
45.	Nome-Bluff	Highly deformed Paleozoic or older metamorphic rocks with many small veins.	Dredging and varied mechanical	L+	L	328 433 533
46.	Koyuk-Buckland	Metamorphic and igneous rocks of Paleozoic and Mesozoic age, cut by granite.	Manual and simple mechanical	M	S	449
47.	Eastern Norton Bay	Nearest outcrops tilted Cretaceous sediments cut by small intrusive masses.	Manual	S	S(?)	449
48.	Candle-Inmachuk	Highly deformed Paleozoic and older metamorphic rocks.	Dredging and hydraulicking	L	L	247
49.	Kougarok	Highly deformed Paleozoic and older metamorphic schists with small veins.	Manual and simple mechanical	M	M	314
50.	Port Clarence	Highly deformed Paleozoic or older metamorphic rocks cut by many small quartz veins.	Manual	S	M	328
	NORTHERN ALASKA-KOBUK:					
51.	Squirrel River	Highly deformed Paleozoic or older metamorphic schists.	Manual	S	S	536
52.	Shungnak	Highly deformed Paleozoic or older metamorphic schists.	Manual	S	S	536

TABLE III.

SUMMARY OF PRINCIPAL LODE REGIONS AND DISTRICTS OF ALASKA.

52.	Shungnak.....	schists. Highly deformed Paleozoic or older metamorphic schists.	Manual	S	S	536

TABLE III.

SUMMARY OF PRINCIPAL LODE REGIONS AND DISTRICTS OF ALASKA.

Reference No.	Name of District.	Character of Ore Deposits.	Mining Conditions and Methods	Past Production, S, small; M, Medium; L, Large.	Reference to U.S.G.S. Bull.
	SOUTHEASTERN ALASKA:				
1.	Hyder.....	Replacement deposits, fissure veins; quartz carrying, free gold with considerable pyrite, galena, sphalerite, chalcopyrite. Near and related to large granitic intrusives of late Mesozoic age. Some Tertiary granitic intrusions.	Fairly accessible to ocean transportations. Moderate costs. Region only slightly developed by relatively shallow shafts and prospecting. Gold recovered by crushing concentrates shipped to smelter in States.	S	807
2.	Ketchikan-Wrangell.....	Contact deposits, fissure veins, stockworks; genetically closely related to granitic bathyliths; low values in free gold associated with sulphides mainly pyrite. Slight secondary enrichment.	Ocean transportation relatively accessible. Sources of hydroelectric power available. Costs moderate. Developments small.	M	347 800
3.	Juneau-Admiralty Island...	Large mineralized tracts following foliation of country rock genetically related to large late Mesozoic bathyliths. Ores in general low grade, containing free gold and some sulphides, principally pyrite, sphalerite, galena, and chalcopyrite, formed at high temperature and considerable depth.	Cheap ocean transportation readily accessible, hydroelectric power available. Low operating costs. Deep shafts and extensive drifts. Large operations. Ore crushed, gold recovered on plates. Pulp concentrated and concentrates shipped to smelter in States.	L+	287 800

TABLE III—*Continued.*

Reference No.	Name of District.	Character of Ore Deposits.	Mining Conditions and Methods.	Past Production, S. Small; M, Medium; L, Large.	Reference to U.S.G.S. Bull.
4.	Chichagof-Baranof.....	Quartz veins in general occupying shear zones in graywackes of Jurassic (?) age. Ore in shoots of irregular form carrying free gold associated with abundant sulphides mainly pyrite. Ores probably closely related to large bathylithic intrusions of granitic rocks of late Mesozoic age.	A few properties developed to considerable depth by shafts and tunnels. Ore crushed and gold recovered on plates; concentrates shipped. Hydro-electric power available.	L	692
	CENTRAL SOUTHERN ALASKA:				
5.	Valdez.....	Both free milling and basic ores. Free milling ores usually in quartz veins with some sulphides, mainly pyrite, and galena with lesser sphalerite and chalcopyrite. Formed at moderate depth, probably closely related to large late Mesozoic granitic intrusives.	Relatively easily accessible to ocean transportation. Costs moderate. District little developed, mostly by shallow shafts and simple milling equipment.	M	622
6.	Western Prince William Sound.....	Free milling gold quartz veins and stringer lodes formed closely following large granitic intrusions in late Mesozoic. Some sulphides, notably pyrite, with some galena, sphalerite, pyrrhotite, arsenopyrite, stibnite, and chalcopyrite.	Ocean transportation could be made available readily. Costs could be moderate. Little developed, mostly by short tunnels and shallow shafts.	S	592

TABLE III—*Continued.*

TABLE III—*Continued.*

Reference No.	Name of District.	Character of Ore Deposits.	Mining Conditions and Methods.	Past Production, S, Small; M, Medium; L, Large.	Reference to U.S.G.S. Bull.
7.	Kenai Peninsula.....	Free gold in quartz veins and stringer lodes, associated with sulphides principally galena, sphalerite, arsenopyrite, and pyrite. Country rock principally Mesozoic (?) slates and graywacke. Not everywhere obviously closely associated with igneous intrusives.	In general relatively accessible to ocean or railroad transportation. Costs moderate. Little developed except by mining or milling equipment of simple type.	S	587
8.	Willow Creek.....	Free gold in quartz veins and stringer lodes lying in and adjacent to large mass quartz diorite. Pyrite in small amounts common. Lesser arsenopyrite, stibnite, chalcopyrite, galena.	Moderately accessible to railroad transportation. Costs moderate. Considerable prospecting, but no extensive developments, principally by tunnels or shallow shafts. Some ore cyanided but most gold recovered on plates.	M	607
	SOUTHWESTERN ALASKA:				
9.	Kodiak-Afognak.....	Quartz veins in slates and granitic rocks which carry some sulphides principally arsenopyrite and pyrite. Some sphalerite. Little chalcopyrite.	Reasonably accessible to ocean transportation. Region little developed and past work has been little more than prospecting by short tunnels and simple crushing devices.	S	542
10.	Unga-Popof.....	Stringer lodes of quartz in andesitic lava of Mesozoic or Tertiary age. Free gold with some pyrite, galena, sphalerite and chalcopyrite. Country rock somewhat pyritized.	Easily accessible to ocean but not on present route of ocean vessels. Practically only one mine has been developed to notable extent, and work there has been suspended for more than 15 years.	M	467

TABLE III—*Continued.*

Reference No.	Name of District.	Character of Ore Deposits.	Mining Conditions and Methods.	Past Production, S, Small; M, Medium; L, Large.	Reference to U.S.G.S. Bull.
	YUKON VALLEY:				
11.	Fairbanks	Narrow quartz veins with irregular high grade shoots. Free gold with small amounts of sulphides, principally stibnite. Two or more periods of mineralization. Near granitic intrusives of Mesozoic and possibly of Tertiary age cutting ancient schists.	Transportation facilities fair. Operating costs moderate. Scale of development small. Shallow shafts and short drifts. Ore crushed and gold recovered on plates. Pulp discarded or impounded	M	662
12.	Kantishna	Free gold in quartz veins cutting early Paleozoic or older schists. Carry some arsenopyrite, pyrite, galena, sphalerite, stibnite, and chalcopyrite. Not recognizably connected genetically with igneous intrusions.	Remote region inaccessible except at heavy expense under present conditions. Costs high. Little developed but available facts indicate probability of high grade ore shoots.	S	687
13.	Chandalar	Narrow fissure veins of quartz in schist containing irregular, high grade shoots of free gold with small amounts of sulphides, principally arsenopyrite.	District remote from main transportation routes. Operating costs high. Small-scale shallow mining. Developments in prospecting stage.	S	773
	KUSKOKWIM VALLEY:				
14.	Nixon Fork	Contact metamorphic deposit carrying free gold with pyrite and chalcopyrite irregularly along quartz monzonite-Paleozoic limestone contact. Surficial enrichment.	District remote and operating costs extremely high. Only shallow development work. Ore crushed and gold recovered on plates and concentrated on tables.	S	783
	NORTHWESTERN ALASKA:				
15.	Seward Peninsula	Low grade shear zones and high grade quartz fissure veins. Gold accompanied by some sulphides, principally pyrite, stibnite, arsenopyrite. Mesozoic and Tertiary mineralization probably associated with deep seated granitic rocks.	District remote and inaccessible by ordinary means during 7 months. Costs high. Only small developments attempted. Shallow shafts. Ore crushed. Gold saved on plates. Simple milling practice or pulp discarded.	S	722

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15. NORTHWESTERN ALASKA: Seward Peninsula.....	Low grade shear zones and high grade quartz fissure veins. Gold accompanied by some sulphides, principally pyrite, stibnite, arsenopyrite. Mesozoic and Tertiary mineralization probably associated with deep seated granitic rocks.	District remote and inaccessible by ordinary means during 7 months. Costs high. Only small developments attempted. Shallow shafts. Ore crushed. Gold saved on plates. Simple milling practice or pulp discarded.	S	722

MOLYBDENITE DEPOSIT AT SHAKAN, ALASKA.[1]

A. F. BUDDINGTON.

THE molybdenite deposit at Shakan, Alaska, is interesting scientificially because it shows an extended sequence of mineralization of a peculiar type, and because it affords evidence as to the position of molybdenite in the succession of sulphide deposition, a subject upon which there are very few data. The sequence of the predominant mineralization for each stage, as evidenced by veinings, successive replacement phenomena, and deposition in vugs, comprises (1) a pegmatite stage consisting largely of orthoclase which has been much granulated; (2) quartz and pyrite; (3) an adularia stage of quartz, adularia, epidote, and calcite with a little disseminated sulphide; (4) the main sulphide period, comprising pyrite, sphalerite, pyrrhotite, chalcopyrite, molybdenite, and chlorite; and (5) a zeolite stage comprising laumontite, calcite, chlorite, and stilbite.

At the time of the writer's visit in 1923 there was no work being done on the property, and only a suite of specimens from the dump were available for study. The deposit has, however, been briefly described by Chapin [2] and by Mertie,[3] and the following description is taken from the report by Mertie.

> The lode is in diorite near the contact with tuffaceous sediments. Pegmatite is present in dikes and veins cutting the diorite and is in fact related genetically to the molybdenite in the lode. The pegmatite is composed essentially of orthoclase feldspar and quartz with accessory sphene and small amounts of secondary sericite, chlorite, and epidote. . . . The gangue of the vein is partly quartz and partly pegmatitic material, and these two appear to grade into one another indicating that at least a part

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Chapin, Theodore, "Mining Developments in the Ketchikan District," U. S. Geol. Surv., Bull. 692, p. 89, 1919.

[3] Mertie, J. B., "Lode Mining in the Juneau and Ketchikan Districts," U. S. Geol. Surv., Bull. 714, pp. 118–119, 1919.

of the quartz is of primary origin. The sulphide minerals in the gangue include molybdenite, pyrite, pyrrhotite, and chalcopyrite. The molybdenite is in some places scattered through the quartz and pegmatite and in others more or less concentrated in a fault gouge zone.

Hess[4] quotes F. W. Bradley as stating that the mineralized zone crops out for 500 feet, that the ore averages from 1 to 2.28 per cent. MoS_2 in large lots, and that 100,000 tons of ore averaging 1.58 per cent. was indicated. The highest grade portions average 12 per cent. molybdenite.

A study of the specimens indicates that the original material was largely a much crushed, coarse-grained, orthoclase pegmatite. A little accessory titanite is present. The orthoclase aggregates are broken and veined and partly to wholly replaced by quartz or quartz-pyrite veins varying from almost wholly quartz to almost wholly pyrite. The pyrite is very coarsely crystalline with cubic habit. At about this stage also, and in part earlier, the orthoclase was partly replaced by epidote, for the epidote aggregates show some replacement by the quartz and pyrite. Occasionally, plumose fans of muscovite replace the orthoclase. The quartz-pyrite veins grade into portions or veins consisting of quartz, calcite, adularia, and epidote with a little accessory titanite, all well crystallized. Where the orthoclase is cut by quartz or calcite veins, the vein boundaries are often lined with rhombs of adularia which project into the vein. In one case, adularia rhombs were also seen to have developed through recrystallization within a large carlsbad twin of orthoclase. Euhedral crystals of adularia are abundant in the quartz and calcite. Quartz occurs as euhedral crystals in the calcite and also with clean cut boundary faces towards the calcite. Rarely the adularia is partly replaced on the edges by calcite or quartz. In some specimens abundant euhedral crystals of epidote are associated with the calcite and quartz. In the hand specimen the adularia shows as small white crystals of pseudorhombic form. Vugs are common in these vein aggregates, and crystals of quartz and adularia, and occasionally epidote with crystal terminations, project into the

[4] Hess, F. L., "Molybdenum Deposits," U. S. Geol. Surv., Bull. 761, pp. 14–15, 1924.

open spaces. Pyrite is locally deposited as incrustations on the quartz and adularia, or the latter two minerals may be encrusted with calcite or finely crystalline chlorite or molybdenite. The pyrite in turn may be coated with molybdenite.

Some specimens consist of abundant small brecciated fragments of the diorite country rock in all stages of replacement by orthoclase and the minerals of the adularia or sulphide stages.

The metalliferous minerals of the main sulphide stage occur in considerable part as local shoots of almost solid sulphide. They replace the silicates. Pyrite and pyrrhotite, for the most part in separate masses, form the bulk of the metalliferous minerals. Microscopic examination shows that pyrite is the earliest sulphide followed successively by sphalerite, pyrrhotite, chalcopyrite, and molybdenite. Sphalerite is not present in the more typical ore, but is an abundant mineral locally. It is veined and in all stages of replacement by pyrrhotite. Microscopic examination shows that disseminated, corroded, crystals of pyrite are common as residual, partly replaced, relics in the pyrrhotite, and that chalcopyrite and molybdenite vein and replace the earlier minerals. Chalcopyrite is a common but not an abundant mineral. Molybdenite is the youngest sulphide, and veins and replaces all the other sulphides. It forms one of the major minerals in the shoots of solid sulphide and is common to abundant as disseminated flakes and veinlets widespread in all the deposit. In the pyritic aggregates it replaces the silicate portion in preference to the pyrite. Chloritization of the epidote and a partial chlorite replacement of the other silicates appear to accompany the introduction of the sulphides.

The last stage of mineralization was the zeolite period. At this time laumontite was deposited on the surface of the adularia crystals and as replacements of the adularia. Chlorite and a fine grained calcite locally replace all the earlier non-metallic minerals, and chlorite occurs filling vein-like interstices between the other minerals. Many of the specimens contain abundant vugs. Adularia rhombs project into these vugs and are coated with calcite crystals that are in turn coated with laumontite. Laumontite is

an abundant mineral at this stage. Stilbite was found in one specimen.

The classification of this vein according to the physical conditions, particularly the temperature, during its formation, raises many interesting points. Lindgren[5] states that adularia is one of the most widespread and characteristic gangue minerals of the epithermal metalliferous deposits (50°–200° C. ±). He, however, groups (p. 641) the veins of the Premier mine in British Columbia, where quartz, adularia, and pyrite are partly replaced by sphalerite, galena, tetrahedrite, chalcopyrite, and sulpho-salts, with the mesothermal deposits (200°–300° C. ±). Parker,[6] on the other hand, groups quartz, adularia, and epidote as among the first minerals to form in the Alpine mineral veins, preceding tourmaline, albite and apatite, and states that for adularia the lowest temperature of formation is known to be 340° C. plus or minus 20° C.

The vein deposit under discussion is obviously of composite origin, ranging from minerals of the pegmatitic stage (573° + C.) to those of the zeolite stage (50°–200° ± C.). The minerals of the adularia period appear to follow the pegmatite stage and to be best grouped, following Lindgren's classification, as of hypothermal origin. In so far as the sulphide minerals themselves are concerned, they might belong to either the hypothermal or mosothermal veins; but since, with the exception of pyrite, they follow for the most part the adularia period and are succeeded by the zeolites, it would seem that they are best grouped as belonging to the mesothermal period, and the minerals of the zeolite period as formed in an epithermal stage.

The writer is indebted to J. B. Mertie for the loan of his notes and specimens from this property.

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[5] Lindgren, Waldemar, "Mineral Deposits," p. 519, 1928.

[6] Parker, R. L., "Alpine Minerallagerstätten," *Schweiz. Min. u. Pet. Mitt.*, 3, 1923, p. 298. Review by Ian Campbell, *Amer. Mineralogist*, pp. 157–167, 1927.

THE DIAMOND DEPOSITS ON THE UPPER ARAGUAYA RIVER, BRAZIL.

FREDERICO W. FREISE.

GENERAL DESCRIPTION.

THE diamond district described in this paper is in the eastern part of the State of Matto Grosso, which forms the two municipalities of Santa Rita do Araguaya and Registro do Araguaya. The diamond deposits take their name from the Rio das Garças (Heron river), one of the left minor tributaries of the Araguaya. About 220 miles to the west is the State capital, Cuyabá; a fairly good automobile road takes the traveler in five days from Cuyabá to the diamond district. This route, however, is not the most frequented one, since the district can be reached from Sao Paulo by rail to Catalão (State of Goyaz) and from there 260 miles over a good road—a journey of four or five days. From Rio de Janeiro the region may be reached within a week.

The district is situated at 16° S. Lat. and is 9° 30′ W. of Rio de Janeiro. The elevation (aneroid) above sea level ranges between 2,950 and 3,060 feet.

The region is a plateau which slopes slightly to the east and is delimited on the west by the mountains Serra do Poguba, Serra de São Lourenço, and further on Serra do Brigadeiro and Serra dos Corodados. The slight variations in level are merely the results of denudation. The vegetation is that of the *campos cerrados* (prairies) with few trees or shrubs. The numerous valleys are deeply cut and precipitous, and even the smallest rivulets have many waterfalls.

GEOLOGY.

An approach to the district from the south reveals very little of its geological character. The soil is a compact ferruginous clay; here and there appear more or less alined blocks of well-

worn quartz with mica. Farther west appear isolated patches of sandstone, presumably the so-called Parecy strata ascribed by some geologists to the Cretaceous. Only from the "Corrego da Colonia" to the east and about 40 miles west of the junction of

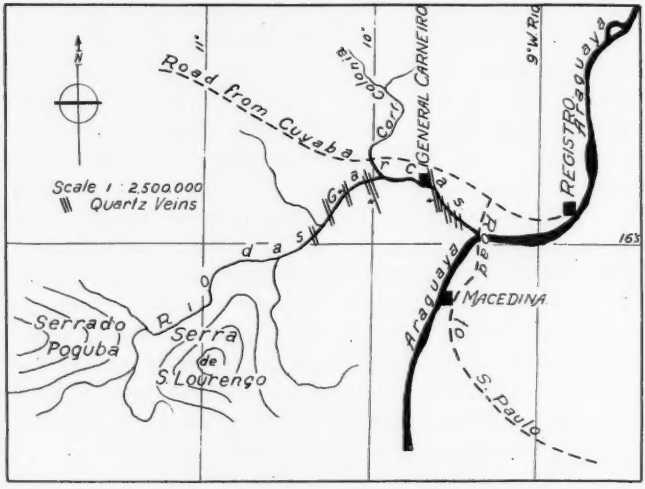

FIG. 1. Sketch map of Upper Araguaya River region.

the Garças and Araguaya rivers, inclined schists are found immediately beneath the plateau alluvium. These schists are intersected by veins of quartz, with intrusions of pyroxenite.

The schists are micaceous, containing, besides quartz and muscovite, tourmalines and strongly altered almandine and pyrope garnet. In the very few places where it was possible to observe the strike of the mica-schist strata, this was found to be N. 30° W.; the dip is about 30° E. The panning of this rock yields magnetite, ilmenite, perowskite, picroilmenite (probably Långbanite), rutile, tourmaline, staurolite of the manganese-bearing variety nordmarkite, and zircon as the heavy residue. The total thickness of the schist is estimated to be 100 to 110 feet.

The intersecting quartz veins strike N. 10° E. and dip 80° W.

They form the rock bars across the Garças River which cause the numerous waterfalls. Within a distance of 18 miles the author traced distinctly 45 of these veins, varying in thickness from 10 to 55 feet. The mineral content of the quartz is limited to large dodecahedral crystals of garnet, black tourmaline in prisms 1.0 to 2.5 inches in length, and pyrite in cubes an inch or more in size.

In the neighborhood of the quartz veins are intrusions of diabasic porphyrites; their plagioclase is clear white or greenish; the pyroxene is brown and forms short columnar crystals; the ground mass is nearly always well crystallized; plagioclase in little bars and globules, or more rarely crystals of augite, form the principal constituents. A little hornblende and liberal quantities of magnetite, titanite and apatite, with here and there some zircon, are the accessories. The extent of these intrusions could not be ascertained.

DIAMOND DEPOSITS.

Up to the present time no work has been done outside of the river bed. The gems are found in gravel deposits upstream from some of the rock bars of quartz veins which cross the Garças River. The mean width of the river is 80 feet, and the average depth of the "bolcas" (pockets) of gravel is about 12 to 16 feet below medium water level (that of April to July). The smallest pockets may contain 10 to 30 cubic yards of material, the more extended ones, 500 to 600 cubic yards. There are innumerable patches of gravel in small crevices and beneath boulders at moderate depths.

All gems thus far found have come from two distinct zones in the river, namely, upstream from the 15th quartz vein—almost two miles east of the "Corrego da Colonia" mentioned above—and between the 28th and the 45th vein, *i.e.* in a length of about one and one half miles from a point 11 miles west of the junction of the Garças and Araguaya Rivers. The intermediate zone is devoid of diamonds as far as is known; about 500 workers found in six months only three rather inferior stones. The associated minerals are the same in both the diamond-bearing and sterile

gravels, so that the strong belief of all native workers that a certain more or less well-defined association of satellites (which they call *formaçao*) is an unfailing indication of the presence of the precious gems, is a mistaken one.

Besides quartz, the pan residues contain all minerals characteristic of schists, such as rutile, anatase, brookite, tourmaline, cyanite, staurolite, garnet of the almandine and spessartine species, hematite, ilmenite, and magnetite. The author by panning hundreds of samples, obtained the following figures which represent the frequency of occurrence of the satellites:

	Per cent.
Quartz	35.00
Rutile	20.00
Tourmaline	15.00
Staurolite	12.00
Ilmenite	8.00
Hematite and magnetite	8.00
Garnet	less than 1.00
Anatase, brookite	.50
Cyanite	.30
Apatite	about .20

In mineralogical appearance these satellites do not offer any peculiarities worthy of mention.

The form in which the king of precious stones occurs in this district was ascertained by the author from the examination of about 200 crystals washed from the Garças River. The simple octahedron is exceedingly rare; rounded dodecahedra are common, but the most frequent forms are the hexoctahedron and the tetrahexedron. Nearly all stones are colorless; since the district was first worked only five or six small yellow stones have shown up.

What may be the mother rock of the diamond in the Garças River is exceedingly difficult to state with any reasonable degree of probability; in any case it is impossible to discover the origin of the gem by considering merely the heavy, dense minerals which accompany it, since numerous unknown factors produced the present mineral association; all accompanying minerals are rounded, but their hardness, toughness, and cleavage are widely

different; above all, the character of the associated bed rock is of the greatest importance.

In order to obtain data for comparison of the qualities mentioned above, the author cut out cubes of the common satellites and subjected them to transport and friction within a rotating drum lined with raw tourmaline imbedded in cement. The minerals were kept constantly submerged and were rolled along the inner walls of the drum until all their edges were rounded. As a previous experiment had proved, this was accomplished when the minerals had lost about 25 per cent. of their original weight.

Let us call L the length of the cube edge, d the specific gravity of the mineral in water, h the hardness, W the way the drum made, or better, z the number of turns to which the mineral was subjected, *i.e.* $z = W/4\ L$, then the total wear R which is to be verified is proportional to the cube of L and to d and W, but inversely proportional to h. Accordingly

$$R = \frac{L^3 \cdot d \cdot \frac{W}{4L}}{h} = \frac{L^2 \cdot d \cdot W}{4h}.$$

With magnetite as a standard (h of magnetite = 100) the results of the tests are condensed in the following table. For the hardest mineral of the series of satellites, tourmaline, the requirement to complete a 25 per cent. reduction of volume, which corresponds to a rounding of all edges, was about 14,150 meters or 30,000 revolutions of the drum, while other minerals require far less.

Mineral.	Spec. Gravity.	Hardness.*	Hardness on transport.†
Garnets	3.4–4.2	6.5–7.5	485–530
Tourmaline	3.1–3.3	7.0–7.5	840–880
Pyroxene	3.3–3.5	5.5–6.0	430–500
Hornblende	3.3	5.0–6.0	380
Zircon	4.4–4.7	7.5	550–580
Rutile	4.2–4.3	6.0–6.5	400
Titanic Iron	4.6–5.3	5.0–6.0	220–250
Hematite	5.2–5.3	5.5–6.5	200–275
Magnetite	4.9–5.2	5.5–6.5	100
Wolframite	7.2	5.5–5.8	450–480
Cassiterite	6.9	6.0–7.0	360–400
Quartz	2.5–2.8	7.0	250–280

* According to Mohs scale. † Magnetite = 100.

Native geologists have surmised that a great torrent once swept over the region, carrying with it a great amount of diamantiferous earth of which the heavier residue was deposited in what is now the Garças River; there is, however, no conclusive evidence for this opinion. Further intensive work is necessary to verify any theory of origin.

HISTORY.

The diamond deposits of the Garças River were discovered in 1920, when a *garimpeiro* (diamond washer) of Bahia found in one of the gravel deposits on the Ribeirão São Lourenço, one of the upper affluents of the Garças, a small stone, absolutely flawless. A rush into the district soon started, but when under the Federal President Epitacio Pessoa a revolution was inaugurated (1922), and armed bands and State troops passed through Matto Grosso, the works were abandoned, as all the workers were in arms. Last year, however, some 1,500 washers, from all the Brazilian States and from abroad, gathered once more on the banks of the river. Since then more capital has been invested in the enterprise. Formerly the gravel gathering in deeper water was done by stout natives, who descended a ladder without any kind of diving outfit and gathered enough material to fill a basket while they could hold their breath. Many lost their lives in this kind of work, which in primitive savagery was precedented only by the old slave divings at Diamantina, Minas.

PRESENT STATE OF THE WORK.

At present several companies are engaged in the work, using modern diving outfits. Where the rock barriers cross the river, cables are fastened from one side to the other; along these move the boats that haul the gravel to the sorting place. The washers work in crews of 5 to 8 men, one or two being professional divers. To loosen the gravel they use crowbars and pickaxes; the gravel is put into bags of 100 to 130 lbs. capacity, and a good diver can furnish 40 to 50 bags in three or four hours. The gravel is washed while all the crew are present, and all findings are at once

acclaimed by dozens of shots fired into the air. The results of the work are divided as follows: 60 per cent. goes to the owner of the diving equipment (a complete outfit costs about $350.00); 10 per cent. goes to the owner of the boat; the balance belongs to the diver. The owner of the diving suit and accessories has to provide his crew with food and housing, both of which are very cheap there. A fat cow can be bought from the Matto Grosso farmers for the equivalent of three to four dollars; beans and rice, the staple native foods, are grown nearby.

EXTENT AND VALUE OF THE DEPOSITS: FUTURE PROSPECTS.

Any attempted estimate of the future of these deposits is uncertain; the author holds the opinion that within a few years the whole affair of the Rio das Garças will be forgotten, as in the case of the Salobro deposits in the southern part of Bahia, where two or three thousand washers exhausted in eight or nine years a considerable deposit of good diamonds. The work is too hard for the non-capitalist, for whom the chance is hazardous; for capitalists the area is too small to justify a large investment. Up to now the Geological Survey of Brazil has paid little attention to the place, the only investigations on the spot having been those of the author of this paper.[1]

RIO DE JANEIRO,
BRAZIL.

[1] Just now, while condensing these notes for publication, I learn of large and valuable diamond findings on the middle Araguaya River, some 250–300 miles north of the described district. It is said that 25,000 washers and adventurers are starting for this new Eldorado. Nothing positive can yet be reported.

EDITORIAL

THE SATISFACTIONS OF FIELD MAPPING.

THE geologist who lives in the country discovers satisfactions peculiar to his situation. He is zesty with purpose and action. He sparkles with the expectation of the unknown. And his health is good, not only bodily, but also mentally. Though he may lack the finest tools, he will correct, through the abundance of his evidence, the deviations caused by his poverty of technique. He will hold within the range of local thought and within a scope where, under that thought, conclusions can be gained. And, being confined to the immediate and the concrete, he will achieve a shrewd, appropriate knowledge, and, from year to year, will build up high in country wisdom.

But another mode of mapping yields satisfactions no less striking. This is the mode of the visitor from the city; it consists of field reconnoissance, enriched and garnished by intervals of association, and of book and laboratory study. Through the additional treatment, the facts are generalized and dramatized. Many are the tales told for their charm; but many also are the sincere struggles toward a science of field occurrence. Though the basis is incomplete, and though it be used with undue codification, still that very condition draws out the flashes of intuitive genius. The city geologist is more daring; he is more learned; he has more ease and pleasure of mind. In the city, rather than in the country, flourish the ideas of process. So attractive, indeed, are the city satisfactions, that most geologists desire them, and universities, government bureaus and corporations have shaped their programs for able men who spend only one or two months of each year in the field.

But neither of these modes is completely satisfying. It is not enough that the geologist measure the earth's surface and draw

lines on paper to imitate its features. Nor is it enough that he speak out, with subtlety and grace, of its hidden past. These opposite studies each have their own appeal. But there is another, and it is more appealing still. I mean that which so combines intensity with breadth that it may be called the field experiment.

This mode requires no less scholarship, no less restraint, and no less time, than the experiment in the laboratory. Here reconnoissance will not serve; for it cannot avoid shaping the pure, disjoined, rude realisms into an elegant but unreal pattern, devoid of experimental value. The affair must go forward laboriously, seriously, and serenely, as an enterprise valuable in itself. It is work for a resident scholar, who will stay at his post in the field, not two months in the year, but ten, and not one year only, but several, if need be, on a single square mile of the earth's surface. Only such a scholar will find the quiet times to read the features of the ground.

Such a scholar, so engaged, will look with no longing toward the city, but will return to it only now and then, to escape again, as soon as the occasion permits. He will neither lose his way in controversy nor drowse among common beliefs. His instinct for the actual will be stimulated to the extreme degree; the fact, in its abundance and vivacity, will crowd out the postulate. With so much known, and so much still to be learned, speculation will for a long time be postponed, and the idea will be made to await the substance.

But this scholar will act no Puritan part. He will not abolish imagination, but control it and set it on reasonable paths, to work toward his goal. He will push fearlessly, to the limit of his reach, into the mobile mechanisms of the earth. He will extend the scope of recorded fact and project more difficult structures to increasing depths. He will brave the test of prophecy, with all its human rewards and penalties, though he sees that the test will be quickly and conclusively applied. He will develop his knowledge beyond the customary routines of mapping: he will devise new means to measure the stresses and strength of the rock. And

so he will build, on his expressionless, flat map, a bolder, more living relief.

When that map is done, we shall have a fragment of the earth, a cosmic sample, to examine in the light of all fundamental knowledge. Only a few such samples, thin disks of ground not more than a mile in diameter, have been taken from out entire planet; these have had a meaning out of proportion to their number and their size, and they have yielded the highest satisfactions of geology. To become the field experimentor, and to multiply such samples, is a career, not only for the future, but for the present also.

AUGUSTUS LOCKE.

DISCUSSION AND COMMUNICATIONS

SUPERGENE CASSITERITE IN BOLIVIAN TIN VEINS.

Sir: in 1926, Mr. F. R. Koeberlin published a paper on the Bolivian tin veins in which he advanced the theory that the ore shoots in many Bolivian tin mines are due to "solution of cassiterite in the upper parts of the veins; downward percolation; redeposition as tin oxide at lower levels." In this and subsequent contributions, he recognized that supergene enrichment of the Bolivian tin veins involves solution of cassiterite and redeposition of cassiterite,—that decomposition of sulphostannates and the formation of wood tin are not quantitatively adequate to explain the phenomena he described. Concerning the quantitative importance of the process of supergene enrichment in the Bolivian veins he wrote in one of the later contributions: "It is perhaps not too much to say that its economic significance with respect to tin lodes is almost as great as that of secondary sulphide enrichment in the case of copper deposits."

These conclusions of Mr. Koeberlin were widely at variance with the views previously held by students of tin veins. If correct, they were of very great economic significance. Furthermore, if supergene cassiterite plays the quantitative rôle ascribed to it by Mr. Koeberlin, it ought not be difficult to find it in Bolivian tin ores. Because of my interest in tin veins, and the Bolivian tin veins in particular, I made a comprehensive survey of the literature on the Bolivian tin deposits, considering the evidence under the four heads, (1) geological, (2) mineralogical, (3) chemical, and (4) textural, in order to find out to what extent the observations of other students of those deposits substantiated Koeberlin's conclusions. A resumé of that survey together with the conclusions that I drew from it was presented

in the June–July, 1929, number of ECONOMIC GEOLOGY. My analysis of the evidence was to the effect that:

1. The geologic evidence is inadequate to establish supergene cassiterite enrichment. Supporting phenomena cited by Koeberlin have been otherwise interpreted by other observers.

2. Mineralogic criteria are of no help because no one has recognized a supergene cassiterite that can be distinguished from hypogene cassiterite. Needle tin does not serve because of its insignificant quantitative rôle.

3. Chemical evidence does not make out a conclusive case either for or against supergene cassiterite. Its existence can not be denied on the ground of insolubility of cassiterite, because both theoretical considerations and recorded observations suggest that under favorable conditions cassiterite may be soluble enough to permit of supergene enrichment.

4. Textural evidence or paragenesis is the least subjective and could furnish the most direct and conclusive proof of the existence of supergene cassiterite. This evidence is entirely against Koeberlin's conclusions. Cassiterite younger than the late hypogene sulphides is not abundant in the Bolivian tin ores.

Whereupon I concluded: "The available evidence does not warrant the conclusion that the Bolivian tin veins present the unusual phenomenon of important supergene cassiterite enrichment."

In the January number of ECONOMIC GEOLOGY, Mr. Koeberlin attacked quite vigorously my analysis of the literature and the validity of my conclusions. I am not unmindful of the fact that copper deposits were worked for many years and studied by many able geologists before the existence and the quantitative importance of supergene sulphides were realized. But it is true that once the geologic evidence of a zone of sulphide enrichment was recognized, it was easy to accumulate convincing paragenetic proof of the occurrence of supergene sulphides. I also appreciate the possibility of preconceived ideas about the insolubility of cassiterite having blinded geologists to the geologic evidence of supergene cassiterite in Bolivia. But I do maintain that once

attention has been called to its existence by Mr. Koeberlin, the rest of us ought to be able to see it. My survey of the evidence was undertaken not to argue for or against Mr. Koeberlin's theory but to try to determine whether it is correct or incorrect, despite Mr. Koeberlin's feeling that my analysis was not impartial. In his discussion of my paper, Mr. Koeberlin has not only failed to grasp the significance of many of the data cited but has misunderstood the conclusions drawn from some of them; and in his attempts to answer them by a *reductio ad absurdum* has drawn some unusual inferences. I am sure that geologists in general have found microscopic paragenetic studies of ores of too great value in elucidating problems of this sort to attach as little weight to them as does Mr. Koeberlin.

The history of Bolivian tin mines is to the effect that it is only the exceptional Bolivian tin vein that can be exploited profitably and that only a small part of a vein contains workable ore. These phenomena, in part at least, account for the "extensive cemetery of defunct Chilean tin companies" that Mr. Koeberlin refers to. These phenomena are not peculiar to the Bolivian tin region, but are characteristic of most if not all mining regions, irrespective of whether or not they contain deposits in which supergene enrichment is of great economic significance. Consequently every mining district has its extensive cemetery of defunct companies. They are defunct because of a great variety of reasons and are not of themselves evidence of an exhausted zone of supergene enrichment.

I do not believe that Mr. Koeberlin fully understood the kind of stope map I had in mind as requisite to furnishing quantitative evidence of the amount of enrichment in the Bolivian veins in view of his statement that he has had "exceptional opportunities to study closely the stope sheets of nearly all the more important producing mines of Bolivia." Stope sheets showing in detail the amount of metal per unit area of vein surface are necessary for such deductions, and data of that character have not been collected even in most of the largest Bolivian mines. Assays on level maps are as far as this kind of information usually goes in any Bolivian mine.

Concerning the mineralogic evidence Mr. Koeberlin says "there is a really remarkable agreement as to the facts observed." With this statement I am in accord, but the agreement is certainly not in the direction believed by him. The agreement is to the effect that secondary tin oxide is the oxidation product of sulphostannates and is usually in the form of wood tin or needle tin. There is also evidence that some needle tin is of hypogene origin. Mr. Koeberlin himself said tin oxide derived from sulphostannates is quantitatively inadequate.

In his discussion of the mineralogic evidence, Mr. Koeberlin cites again the decrease in tin and increase in sphalerite with increasing depth in the Salvador mine near Pazña, and says if the rich tin zone is hypogene this makes a mess of the zonal theory. But the zonal theory is not so inevitably impaled. It does not suffice to describe the vertical sequence without regard to the paragenesis of the minerals involved. The Salvador mine case may be analogous to the relations at the Caracoles mine which Dr. Robert M. Overbeck has described to me. He found there an increase in sphalerite at the bottom of the cassiterite ore shoot; but the sphalerite is later than the cassiterite. In other words, sphalerite was deposited at a lower level but later than cassiterite, and, therefore, entirely in accordance with the zonal sequence.

The discussion of the chemical evidence by Koeberlin is knocking down a man of straw. The section of my paper on this topic discusses (1) the solubility of cassiterite in general and (2) the probability of exceptional behavior of Bolivian cassiterite because of its greater impurity and its unusual mineralogic associations. The phrase "preponderant evidence against solution" to which Mr. Koeberlin takes exception very clearly refers to the cumulative evidence of the past, and in the same sentence I discounted its applicability to the Bolivian problem. And my next sentence is "There is positive evidence of the solution of cassiterite and of the presence of an appreciable quantity of tin in supergene mine waters." Further than this, chemical evidence of the solubility of cassiterite can not go. But proving a certain degree of solubility of cassiterite is not yet proof of the deposition of super-

gene cassiterite on a scale to give it great economic significance. I was not, therefore, challenging the solubility of cassiterite in supergene waters (a fact which I had just admitted as proven) when I concluded that "available evidence does not make out a conclusive case either for or against the deposition of supergene cassiterite." In the misunderstanding of what I wrote, Mr. Koeberlin here lost sight of the fact that solution of a mineral is one step in the process and redeposition of the mineral is another. The second step is not a necessary consequence of the first, and even if redeposition does follow it may be far from complete. Sphalerite is a striking example. It is very soluble in supergene waters, but is not deposited to nearly the same extent as a supergene sulphide.

Mr. Koeberlin rightly attacks most vigorously the paragenetic evidence. In his attempt to minimize the importance of this evidence, he apparently realizes that his case must ultimately stand or fall on it. He first challenges the criteria for distinguishing supergene from hypogene cassiterite. The *sine qua non* for supergene cassiterite is certainly the deposition of cassiterite on the latest minerals of the hypogene sequence (these being the sulphides and silver minerals); and if the process is of *great economic significance,* the deposition must be in considerable quantity. Mr. Koeberlin attempts a *reductio ad absurdum* of the first criterion by applying it to a banded ore from Potosi consisting of layers of cassiterite alternating with layers of stannite, tetrahedrite and pyrite. According to that criterion he says the cassiterite following a band of tetrahedrite should be supergene, yet, he believes in this instance both minerals are hypogene. He concludes this "merely goes to show the untrustworthiness of the proposed criterion." It is hardly credible that he did not realize that the layer of cassiterite is older than the next layer of tetrahedrite, that both minerals occupy the same position in the paragenetic sequence, and that alternating banding is not what Boydell meant by "the deposition of cassiterite on later minerals of the paragenetic sequence." He also fails to see how the quantity factor can be applied in a slide. Of course, the amount of super-

gene cassiterite seen in a given slide is immaterial; the evidence for "considerable quantity" is built up mainly through its repeated occurrence in many slides. The answer to his question which immediately follows, would in the Salvador ore "a slide or polished section showing a deposition of cassiterite on zinc sulphide make this cassiterite any more convincingly supergene?" is undoubtedly "yes." Koeberlin's prediction that my answer would be "no," because I attach no weight to the occurrence of needle or honey tin on wurtzite, is another manifestation of the failure to grasp the significance of the evidence. Needle or honey tin is a mineralogic curiosity, and whether it is supergene or not has little to do with the question of whether supergene cassiterite is of great economic significance. It is for this same reason that I am left "unimpressed" by the bones partially replaced by cassiterite in so far as the subject under discussion is concerned, and not because it is "hopeless to find any mineral late enough in the paragenetic sequence to be convincing" to me.

Mr. Koeberlin next attacks the material that has been subjected to paragenetic study as not having been representative and not having been collected with this problem in view. For these reasons he says it has failed to show supergene cassiterite. My own collections, which were studied by Dr. Hall, do not consist of "the showy, pretty pieces with clear-cut crystallization, which by their very nature are more likely to be of hypogene origin," but are illustrative of the ores that are actually produced from the Bolivian mines. According to Koeberlin's theory they must contain supergene cassiterite in sufficient abundance for it to be of great economic significance. The suites of ores collected by Lindgren and described by him and his associates were undoubtedly also collected as ore specimens and not as mineral specimens. If equally extensive collections were made from copper deposits that were workable only in the zone of supergene enrichment, the microscope would reveal the deposition of the supergene minerals after that of the hypogene. It would not "require painstaking care and judgment in the selection of the sample" to secure specimens showing supergene copper minerals; far more difficult

would it be to collect a suite of specimens which did not show such evidence. If, as Koeberlin maintains, supergene cassiterite is of almost as great economic significance as secondary sulphide enrichment in copper deposits, the same should be true of suites of tin ores. For that reason I characterized as "imposing" the evidence against supergene cassiterite enrichment. Furthermore, I had taken into consideration only the published evidence. I have since learned that suites of specimens have been collected for the purpose of elucidating this specific problem, and their study has yielded only negative results.

Koeberlin's final attack on the paragenetic evidence is to question the interpretations and conclusions in individual cases. The reference to Davy's consideration of the source of the tin in "wood tin" is not pertinent in that the question at issue involves secondary cassiterite that is not in the form of "wood tin." The point of Winkelmann's work is lost because of incomplete statement of his findings, and Koeberlin's inference is consequently invalid. Winkelmann found two generations of sulphides, an older consisting of arsenopyrite, pyrite, and marcasite, and a younger group of sphalerite, galena, and chalcopyrite. Cassiterite is older than both. The hypogene origin of the cassiterite depends not alone on the origin of the marcasite, but on that of all the members of both groups of sulphides. The cassiterite could be supergene only if all of these sulphides are supergene. In this paragraph, he refers again to repeated cycles of cassiterite and stannite as described by Kozlowski and Buerger and Maury and repeats the amazing statement that because second cycle cassiterite must necessarily be younger than first cycle stannite, the criterion by which one mineral can be placed later than another in the paragenetic sequence is invalidated.

Koeberlin objects to the citation of evidence from the Colorado vein at Chocaya because he had already classed it in his first paper as an outstanding example of a primary vein. It is true that the absence of supergene cassiterite there has no direct bearing on its occurrence somewhere else. Nevertheless a consideration of this vein is instructive. In the Oploca ground it consists of

pyrite, cassiterite, and quartz in the order of their relative quantities, but included a silver ore shoot in which occurred in addition the usual assemblage of sulphosalts including stannite. In the Las Animas mine of the Aramayo Company, the sulphosalts are much more abundant and silver values exceed the tin. This one vein presents, therefore, in its various parts almost all of the mineral assemblages represented in those Bolivian mines which Koeberlin cites as examples of supergene enrichment. It contains much marcasite, the vein is open textured, there is an abundance of water in the mine, it is in a non-glaciated portion of the Cordillera. Is it not worthy of emphasis that supergene cassiterite has not been deposited in this vein?

The last paragraph comments on my use of the "qualifying adjective 'important'" throughout the paper. I used this adjective in order to keep the problem clearly before the reader. The purpose of the paper was not to determine whether occasionally a little supergene needle tin or honey tin was deposited, nor was it to determine whether tin oxide occurs as a product of the breaking down of sulphostannates under supergene conditions, nor did it matter if cassiterite partially replaced a bone. The purpose of the paper was to test the validity of Koeberlin's assertion that the deposition of supergene cassiterite is of great economic significance. It was for that reason that I was searching for evidence of "important" cassiterite enrichment. In this discussion I have followed his own phraseology and used the term "of great economic significance" instead.

The subject of supergene cassiterite in the Bolivian veins is discussed in a recent paper by R. Pilz and M. Donath in the *Zeitschrift für praktische Geologie*, 1929, pp. 135–137, in which Koeberlin's theory is also refuted.

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ORIGIN OF CHROMITE.

I HAVE been greatly interested in the papers by Edward Sampson and C. S. Ross[1] in a recent number of ECONOMIC GEOLOGY and also in the discussion thereupon by J. T. Singewald, Jr.[1]

As I have had considerable experience in the mapping of the Rhodesian chromite deposits, I may perhaps be permitted to make a few remarks based upon my study of these occurrences.

Mr. Sampson quotes the late A. E. V. Zealley with regard to the manner of occurrence of the Selukwe deposits, and states his own opinion that they were probably formed by replacement, the agent being "a late formed liquid which deposited talc and chromite metasomatically."

I am quite unable to agree that the origin of the talc, or rather the talc-carbonate schist, is related either in mode or time to that of the chromite. During an intensive study of the Shabain asbestos area, in which low-grade chromite also occurs, I was forced to the conclusion that the talc rocks were formed later than the serpentine rocks of the area, principally by the dynamic metamorphism of the serpentinized dunite due to the intrusion of the great granite batholith of the area. A study of the geological map published with the Southern Rhodesia Geological Survey Bulletin No. 3, dealing with the Selukwe area, shows that a similar mode of origin for the talc rocks of that area is also possible, the ultrabasic rockmass having been intruded by both gneissic granite and the still younger Mont d'Or granite.

Furthermore, deposits of chromite of smaller size but otherwise similar to those at Selukwe, occur at Mashaba, some 40 miles to the southeast from Selukwe. These deposits occur in untalcified serpentine rock of apparently the same age as that of Shabain and Selukwe. It may be mentioned that these three places are at the apices of an equilateral triangle and are of very similar geology. It appears probable that the chromite was emplaced prior to both serpentinization and talcification of the peridotites and dunites in which it is now found.

The chromite occurs in the form of isolated lenses which have

[1] ECON. GEOL., vol. 24, pp. 632–649.

been proved during mining operations to cease when followed downwards, as abruptly as when followed toward the sides. Many lenses do not outcrop but have been cut in adits driven into the hillsides to open up other lenses which do outcrop. This fact alone is evidence against an origin by replacement. Rather do I believe that the deposits represent segregated chromite which occurred in the ultrabasic magma before its intrusion, as suggested by Vogt in his work upon various irregular deposits of chromite and magnetite in Europe. The segregation must be supposed to have taken place in the magma chamber, the molten chromite and peridotite being injected contemporaneously. In those portions where the chromite liquid was on the edge of the intrusion a local replacement of the conglomerate and grit mentioned by Zealley may well have taken place. This is not evidence in favor of the view that the lenses of chromite as a whole are younger than the enclosing serpentinized and talcified peridotites.

With regard to Figs. 2 and 3 of Mr. Sampson's paper, similar occurrences of chromite-rich enstatite-dunite serpentine occur in the hanging and footwalls of the chromite seams in the Great Dyke of Southern Rhodesia. That these regular seams were formed by replacement is almost unthinkable, as is apparent to anyone who has studied the occurrences. As for the statement that " the chromite-free portion is dunite partly altered to serpentine, but that in the chromite-bearing portion serpentinization is complete," surely that fact cannot be advanced as proof that the chromite is younger than the dunite. Rather is the complete serpentinization near the chromite due to the fact that owing to the difference in competence between the chromite-poor and the chromite-rich dunite, any earth movement would naturally cause an incipient fracturing between these two types, thus affording an easier path for the serpentinizing waters along the edges of the chromite-rich dunite. Or so it appears to me.

Mr. Sampson's explanation of the Bushveld Complex occurrences described by the late Dr. P. A. Wagner (Figs. 5 and 6) cannot be applied to the similar deposits of the related Great Dyke, dealing with which a bulletin of the Southern Rhodesia Geological Survey will shortly be published.

During the visit of the XVth International Geological Congress to South Africa and Rhodesia this year I had the pleasure of making Mr. Sampson's acquaintance and, knowing that he visited both the Bushveld Complex and Selukwe, I hope that in view of his personal experience of the southern African chromite occurrences, he will do me the honor of a reply to this communication stating in what respects, if any, his views have changed since 1927.

With regard to C. S. Ross' paper, an interesting parallel with the zonal arrangement of the Webster dunite and associated talc and secondary amphibole rocks is the Shabain ultrabasic rock-mass. Here again I see no reason why the chromite may not be contemporaneous in origin with the olivine. The association of the chromite and of the stated secondary hydrothermal minerals (many of which are formed principally by dynamic metamorphism in the presence of heated waters and vapors) and of the shear planes in the dunite, may quite probably be due to the same cause I have already mentioned, the likelihood of any fracturing or shearing being localized along the contacts of the dunite and the chromite. In the Great Dyke many exposures may be seen showing that the contacts of the chromite seams and the serpentine rock are planes of weakness, planes which have been taken advantage of by later dolerite intrusions.

In fact, the chromite may be the cause of the observed localization of the shearing and metamorphism rather than the shearing being the cause of the localization of the chromite. That the localization of the shearing may be the cause of the formation, where found, of the talc, anthophyllite, biotite, etc., etc., I am quite prepared to admit, but of the chromite, no, unless further evidence can be brought forward in support of that hypothesis.

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A SIMPLE DIAMOND SAW.

THE diamond saw described in this article is a metal disc the edge of which is charged with diamond dust. The saw at 1,000 revolutions per minute or more will cut any mineral including diamond. A diamond saw is ideal for cutting mineral specimens either for thin sections or polished surfaces. The method for making a diamond saw that I wish to describe is in use in commercial laboratories. I do not believe, however, that it is generally known by workers in university or college laboratories of geology and mineralogy. The method has recently been tried out in the Laboratory of Economic Geology at Harvard and proved very satisfactory. No more than fifty cents is invested in the saw at one time. Accidental damage to the saw means little loss. In every way it is inexpensive to operate, easy to make, and cuts about as well as the expensive diamond saws bought ready-made. The materials needed are: a thin ductile metal disc, a small steel roller for charging the saw, and some diamond abrasive.

Any ductile but strong metal can be used for a diamond saw. I used cold rolled copper, that can be bought in any sheet metal shop; 16 ounce copper which measures about .02 to .03 inches thick is heavy enough and yet not too thin for a diamond saw. Very thin copper is too easily damaged to be satisfactory, except when exceedingly thin cuts are necessary. Diamond cutters use very thin saws to minimize loss when cutting diamonds; this is not necessary with laboratory specimens of ores.

The diameter of the saw depends on the motor speed to be used. A saw 5 or 6 inches in diameter cuts well when run at the average electric motor speed of 1,725 R.P.M. The metal disc to be used must be flat and cut true. Such a disc can be easily made on a lathe. If instead it is to be cut by shears, the disc should be first cut a half inch too large and then cut off in narrow strips until the desired size is cut; in this way the disc will not be bent at the edge. The arbor hole can be cut with an auger wood bit. First a small hole is made for the bit feed screw; then the bit is turned until a groove is cut half through the copper from one side, after

which the hole is completed by cutting through from the opposite side. It is best to cut the hole a little small; it can then be enlarged with a pocket knife to fit the shaft of the motor. The disc is finally trued up after it is in place on the motor. This is done, while the disc is turning, by holding a file or piece of carborundum against its edge.

The saw will bind if it does not have a "set" that is, if its cutting edge is not wider than the body of the disc. To set the saw, the edge of the disc parallel to the radii is lightly but firmly pounded with a light hammer. In this way a uniform flange is made. The disc is now ready to be charged with diamond dust.

A case-hardened steel roller is used to force the diamond particles into the edge of the copper disc. A roller an inch wide and an inch in diameter fitted to run smoothly on a shaft fastened to a handle is very convenient. A small ball bearing unit from an automobile generator discarded by a garage, makes an inexpensive tool for the purpose.

Diamond dust can be bought for $5.00 to $6.00 per carat from Arthur Crafts Co., 125 Summer Street, Boston, Massachusetts. Two grades of diamond dust were tried, No. 1 and No. 2. No. 1, measures about .008 to .01 mm. and No. 2, .02 to .04 mm. I tried these two grades and had good results with No. 1, but No. 2 seemed too coarse and gave only poor results. To prevent loss and make it easy to handle, the diamond dust is mixed to a thin paste with olive oil.

To charge the saw attach the copper disc to the motor, coat the steel roller with the diamond paste. Press the roller against the edge of the disc forcing the diamond particles into the copper. When first pressing the roller against the disc it is well to turn the disc several revolutions by hand. Then with the motor running the charging is completed. Less than a minute is required to charge the saw. The amount of diamond abrasive needed for charging the saw is very small. If an excess is used on the roller the diamond is lost. If too little is used and the saw does not cut very well a second small charge of abrasive is applied. It is, therefore, more economical to use too little to begin with than to use an excess.

When cutting the edge of the saw must be kept wet. This is best accomplished by having the saw's edge pass through a wet sponge. The pressure of the specimen on the edge of the saw must be steady and not too great. With excessive pressure the diamond particles will be torn loose and make frequent recharging necessary. The specimen to be cut should be fastened in a holder so that it may be held with a constant pressure against the saw. In this way a very flat smooth surface can be cut and it also prevents accidental damage to the saw. If the specimen is held in the hand only uncertain results can be expected. To operate a diamond saw is not difficult; only a little experience in cutting is necessary to get excellent results.

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REVIEWS

The Mother Lode System of California. By ADOLPH KNOPF. U. S. Geol. Survey, Prof. Paper 157, 1929. Pp. 88, pl. 12, figs. 26, map.

The famous zone of gold-bearing quartz veins, which extends for 120 miles along the foot-hills of the Sierra Nevada, has been restudied by Dr. Knopf and the results form the basis of his recent paper, which presents the most comprehensive and unified picture of the geology and ore deposits of the Mother Lode belt that has yet appeared. The new work in the field was concerned primarily with the ore deposits themselves, and supplements in an admirable way the more general geological investigations completed by Ransome about thirty years ago.

The major features of the geology, established by the earlier workers, are confirmed by abundant new evidence. The contrast between the intense metamorphism of the Calaveras formation and the feebler alteration of the Mariposa sediments and interbedded pyroclastic rocks is particularly emphasized. The green schists and greenstones of the two formations receive especial attention due to their importance in relation to the ore bodies, and the argument for the existence of intrusives of pre-Mariposa age is strengthened by convincing data. The abundant serpentine of the region is regarded as the "basic prelude" of the great Sierran batholithic intrusives at the close of the Jurassic.

The fissures to which the Mother Lode mineralization is related are considered to be series of auxiliary fractures in a zone parallel to a great and persistent reverse fault. The fractures generally break across the grain of the country at acute angles, both in strike and dip. In passing from slate to greenstone or to other more massive rock, the fractures tend to be deflected toward the normal to the contact. In Amador County, the bend is so constant a feature that a rough value for the index of refraction was computed for it (viz. 1.4).

The gold-bearing quartz veins are attributed primarily to the filling of open cavities along the fissures. Clear evidence exists of renewal of movement and reopening of fractures during mineralization, with enlargements of the veins by successive deposition of material. Further movements, continuing after the close of mineralization, produced the thick layers of gouge that accompany most of the veins and are responsible for the heavy ground characteristic of the Mother Lode mines.

Replacement is considered to have been of little significance in the formation of the veins, but was the dominant process in the alteration of the wall rocks. The introduction of abundant ankerite is the outstanding

feature, regardless of the original rock. Sericite and albite are most prominently developed in the greenstone, in which the alteration is generally most complete. In the slates, the ankerite tends to form small lenticular kernels, through which the original banding of the rock can still be traced by layers of unreplaced carbon. Shearing later than the alteration is unmistakably shown by the rotation of the carbon layers and by the circumfoliation of the adjacent slates. Pyrite on the other hand cuts sharply across the texture of the rock.

Gold occurs in ore shoots in the quartz veins, with the altered wall rock usually barren, or in carbonatized schist and greenstone, ("gray ore"), generally with neighboring quartz veins barren. The ore shoots on the veins are relatively short along the strike (usually 200 to 300 feet), but many have been followed for great distances along the steep pitch or rake (present maximum about 5,000 feet). The ore shoots generally coincide with the thicker parts of the quartz veins, and the grade decreases abruptly where veins pinch or fray out into stringers. There is some tendency for ore shoots to follow or to be parallel to splits and intersections. This is particularly true of "gray ore," which occurs most commonly in wedge ends of greenstone masses between converging veins. Slate and barren quartz veins may form sharp boundaries to "gray ore" bodies, but limits of ore are gradational against carbonatized greenstone and can be determined only by assay.

The hypothesis is proposed that the quartz, which forms the great bulk of the vein filling, was supplied from the wall rocks as the result of the displacement of silica by carbon dioxide. The latter and the gold are attributed to exhalations that issued at high temperature from a deep-seated consolidating granitic magma. The waters by which these materials were transported are considered to have been derived only in part from the magma and to have come largely from the meteoric circulation. "The motive power for causing this 'magmatic water' to rise was doubtless the gravity potential of a meteoric circulation whose paths were determined by the fissure systems." (!) The origin of the long ore shoots is attributed to the localization of active flow of the ore-depositing solutions to relatively narrow courses along the fissure, determined by the release of the thermal waters at the surface only through certain local orifices as well as by structural features of the fracture, in particular the size and continuity of cavities. The erratic distribution of gold, which unfortunately is a fairly common characteristic of the ore shoots, is attributed to the switching of the rising solutions from one pathway to another, due to the influence of intermittent movements on the distribution of cavities.

The reliance on lateral secretion for the quartz and on the meteoric circulation for the transporting agency is surprising and interesting in this heyday of magmatic theories. Undoubtedly, a great supply of silica was

made available by the alteration of the wall rock, and the problem of its disposal must be faced by the geologist who attributes the quartz of the veins to deeper sources. However, the proposed hypothesis has some difficulties of its own to face. In general, the derivation of the quartz from the walls seems to complicate rather than to aid in the interpretation of the evidence bearing on the problem of ore shoots. Increasing dryness of the mines with depth, which seems to be the rule of the region, is difficult to harmonize with the important part assigned to meteoric waters in the transportation of material. The author emphasizes the possibility of strong flows on fractures, and apparently assumes that meteoric water would be available at great depth from such sources. It must be admitted, however, that the terms meteoric circulation and lateral secretion have a somewhat dreadful reminiscent sound these days and that reliance on such processes, even in the, shall we say, coöperative magmatic way urged by Dr. Knopf in explaining the formation of the gold-quartz veins of the Sierra Nevada region, is hardly likely to prove acceptable to the younger generation of ore geologists.

The paper contains an abundance of significant data, clearly presented not only in the text but on many maps and sections. The mine manager may be somewhat disappointed by the lack of exact formulation of guides to ore. But that, after all, is properly the function of the practicing geologist whose job it is to express the broader principles, established by government surveys, in the more specific quantitative terms necessary for effective application to operating needs. The paper offers a store of useful material and stimulating ideas capable of being of important service in economic problems of the region, as well as being of high value to all workers in the science.

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Vorkommen und Geochemie der mineralischen Rohstoffe. By GEORG BERG. Pp. vii + 414, figs. 67. Akad. Verlagsgesellschaft M. B. H., Leipsig, 1929. Price, 28 Marks.

In this volume the materials forming the minerals in the earth's crust are discussed from the geochemical standpoint. The general part treats of the distribution of the elements in the earth, their concentration into minerals, and the concentration of minerals by the cooling of magmas, by weathering and by sedimentation.

In the special part the elements are divided into light metals, noble earths, steel-iron metals, not-iron metals, non-metals and noble gases, and the different members of each group are briefly discussed. Their geochemical attributes and distribution in the earth's body are described and

their manner of occurrence and principal deposits are outlined, in some cases in considerable detail. The book is thus a new kind of Economic Geology, in that it emphasizes deposits of elements rather than those of its compounds. The book is particularly interesting to English-speaking geologists because of the thoroughness with which it describes European, Asiatic and African deposits, for its wealth of references and for its thorough discussion of the chemical processes involved in the deposition of most substances. It is well worth reading.

W. S. BAYLEY.

Organic Evolution (Revised Edition). By R. S. LULL. Pp. 743, figs. 265, pls. 31. The Macmillan Co., New York, 1929. Price, $4.50.

The second edition of this well known book consists of three parts: (1) Introduction, 5 chapters, on the history of evolution, classification of organisms, and geographic, bathymetric and geologic distribution; (2) The Mechanism of Evolution, 7 chapters; and (3) The Evidences of Evolution, 28 chapters. Part 3 is divided into 3 sections dealing with (1) ontogeny, (2) morphology and adaptations, and (3) paleontology. The section on paleontology has 16 chapters, all but three of which deal with vertebrate paleontology.

The arrangement of subject matter in part 2 is somewhat different from that in the earlier edition. The classification of the Saurischian dinosaurs has been modified. The carnivorous dinosaurs are divided into two suborders Coelurosauria and Pachypodosauria. Genera which were formerly referred to the Theropoda are divided between the two suborders. The Protodonta, formerly considered Triassic mammals, have recently been shown to belong to the cynodont reptiles because of the indication of a complex lower jaw. No mention is made of the recent discovery of several skulls of Mesozoic mammals in Mongolia.

The most important additions are two chapters dealing with "Cetaceans" and "South American Mammal Radiation." The chapter on Cetaceans treats of their place in nature, characteristics, habitats, habits, and evidences of evolution, and gives a systematic review of the phyla and more important genera of the whales. This subject has not been discussed heretofore in texts on paleontology and evolution. The subject of "South American Mammal Radiation" is also a welcome addition to the book, even though it has already been well treated by Scott in "History of the Land Mammals of the Western Hemisphere."

The paleontological discoveries in Mongolia during the past ten years are given only incidental mention. Reference lists at the ends of the chapters have been brought up to date.

The incorporation of the more important new discoveries of the last

twelve years makes this revised edition the most authoritative and readable book on evolution and vertebrate paleontology available.

HAROLD R. WANLESS.

Deposition of the Sedimentary Rocks. By J. E. MARR. Pp. vi + 245, figs. 8. University Press, Cambridge, England, 1929.

The author presents a general treatment of sedimentary rocks, emphasizing "the conditions that have controlled the distribution of the various kinds of sedimentary deposits in time and space." There is a brief explanation of the significance of the term "chronology" and of the value of fossils in correlation, and a discussion of the proper use of lithology and fossils as indices of the physical conditions prevalent during the formation of the deposits. The main part of the volume is devoted to descriptions of the characteristic features and areal distribution of sediments accumulated on land surfaces and at the bottom of seas and other large bodies of water, at shallow, intermediate and great depths. The effects of land oscillations, of shore currents, of deltaic processes, of shore-line irregularities, of estuarine conditions and of climatic belts upon the processes of sedimentation are all disclosed, and the characters impressed upon the resulting sediments are pictured. The book is not a text book, nor a treatise on sedimentary rocks. It contains but few references to the literature, and the rocks cited to illustrate the principles developed are limited almost exclusively to districts within Great Britain or Northwestern Europe. However, the volume is an excellent supplementary text for students of sedimentation.

W. S. BAYLEY.

Applied Geophysics in the Search for Minerals. By A. S. EVE AND D. A. KEYS. Pp. 253, figs. 92. Cambridge University Press, 1929.

This book is recommended as an easily readable elementary textbook for elementary classes in geophysics and as an interesting and readable account of geophysical prospecting for the geophysical layman. The geophysicist specializing in one or two methods will find much of interest in it. Although elementary, it has considerable depth. It describes the instruments and methods of the magnetic, electro-magnetic, electric, and seismic methods in relatively simple terms, in pleasingly readable English, and with restraint against too much superfluous detail and too much highbrow conciseness. Not all parts of the discussions of the mathematical theory will be followed by the average engineer or student without assistance. Many of the comments on the seismic method are considerably out of date. The connection of micropaleontology and diamond

drilling with geophysics seems rather attenuated and not so close as the unmentioned petrography.

DONALD C. BARTON.

Economic Geology. By H. Ries. 6th edition, revised. Pp. 860, figs. 291. John Wiley & Sons, New York, 1930 (Jan.). Price, $6.00.

This excellent text is too well known in its previous editions to need review. Its author has been assiduous in keeping it up to date. Seventeen pages have been added to the new edition, several new figures are included, all statistical matter has been brought up to date, and new references and localities have been included. It now fully reflects the progress of the subject in its field. The half that deals with non-metallics is particularly valuable, since it reflects the author's special interest and is authoritative. It is a valuable book for reference and class room and should continue to hold its well deserved place in the literature of economic geology.

ALAN BATEMAN.

The Universe Around Us. By SIR JAMES JEANS. Pp. 341, pl. 24. The Macmillan Company, New York, 1929. Price, $4.50.

This distinguished scientist has written for the lay reader in a charming and non-technical style about the mysteries of modern physics and astronomy. He deals with the methods and results of modern astronomical work and points the way to the conclusions that can now be reached as to the past and future of the earth, the duration of life, the structure of the atom, and the origin of the heavenly bodies. The chapter headings give some idea of the context; they are: Exploring the Sky; Exploring the Atom; Exploring in Time; Carving out the Universe; Stars; Beginnings and Endings.

It is an interesting book and one that every educated man with an inclination toward science should read.

A. M. B.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

BOOKS RECEIVED.

BY

F. S. PARKER.

The Mohave Desert Region, California; A Geographic, Geologic, and Hydrographic Reconnaissance. By D. G. THOMPSON. Pp. 759, pls. 34, figs, 20. U. S. Geol. Survey Water Supply Paper 578, 1929. Price, $2.00. General and local discussion of geography, mineral resources, climate, stratigraphy, structure, geologic history, ground water, and notes on desert travel. A reconnaissance geologic map and several relief maps showing watering places form part of the report.

Petrography of the Pioche District, Lincoln County, Nevada. By J. L. GILLSON. Pp. 9, pls. 1, figs. 3. U. S. Geol. Survey Prof. Paper 158-D, 1929 (Jan., 1930). Price, 10 cts. An interesting discussion of differentiation and endomorphism in the Quartz Monzonite.

Southern Rhodesia Geol. Survey, Bull. 15, I. The Geology of the Central Part of the Wankie Coalfield, by B. LIGHTFOOT. II. The Fossil Flora of the Karroo System in the Wankie District, by J. WALTON. Pp. 83, pls. 13, figs, 4, map. Salisbury, 1929 (Jan., 1930). General and economic geology, including discussion of petrology, stratigraphy, clay, building stone, etc. A geologic map and section of the Central Wankie Field accompanies the report.

The Helderberg Group of Parts of West Virginia and Virginia. By F. McK. SWARTZ. Pp. 48, pls. 4, figs. 6. U. S. Geol. Survey Prof. Paper 158-C, 1929 (Jan., 1930). Price, 20 cts.

Geology and Ground-Water Resources of North Dakota. By H. E. SIMPSON, with a discussion of the Chemical Character of the Water, by H. B. RIFFENBURG. Pp. 312, pls. 3, figs. 10. U. S. Geol. Survey Water Supply Paper 598, 1929 (Jan., 1930). Price, 50 cts.

Gypsum Resources and Gypsum Industry of New York. By D. H. NEWLAND. Pp. 188, figs. 59. N. Y. State Museum Bull. 283. State University, Albany, 1929 (Dec.). Geology, origin, and industrial methods.

Florida State Geological Survey, Twentieth Annual Report. Pp. 294, pl. 40, figs., map. Tallahassee, 1929 (Dec.). Statistics of mineral production; geology of the State, with geologic map; extinct land mammals.

Preliminary Report on Woman River and Ridout Map-Areas, Sudbury District, Ontario. By R. C. EMMONS and ELLIS THOMPSON. Pp. 30, maps 2. Canada Geol. Survey Mem. 157, Ottawa, 1929 (Dec.). Price, 10 cts. Description; general geology; economic geology; geologic maps.

Bear River and Stewart Map-Areas, Cassiar District, B. C. By G. HANSON. Pp. 84, pls. 5, figs. 14, maps 2. Canada Geol. Survey Mem. 159, Ottawa, 1929 (Dec.). Price, 20 cts. General description; general geology; economic geology, with special attention to copper and silver-lead-zinc deposits.

Report on Pocahontas County, W. Va. By P. H. PRICE. Pp. 531, pl. 71, figs. 21, maps 2. West Virginia Geol. Survey, County Reports, 1929. Morgantown, W. Va. 1929 (Nov.). History and physiography, geology, mineral resources, paleontology, levels, geologic maps.

Native Road Materials and Highway Maintenance. By N. E. WOLFARD. Pp. 42, pl. 12, figs. 2. Okla. Geol. Survey, Circ. 20. Norman, Okla., 1929 (Nov.).

The Contact of the Fox Hills and Lance Formations. By C. E. DOBBIN and J. B. REESIDE, JR. Pp. 25, pl. 2, figs. 4. U. S. Geol. Surv. Prof. Paper 158-B, 1929 (Nov.). Comprehensive treatment; the writers believe that the contact is transitional and that volcanic ash is not present in the Colgate sandstone.

A Chemical Study of Oklahoma Coals. By J. E. MOOSE and V. C. SEARLE. Pp. 112, pl. 7, fig. 1. Okla. Geol. Surv. Bull. 51, Norman, Okla., 1929 (Nov.). Geology; chemical studies; description of mines.

Investigations of Fuels and Fuel Testing, 1927. Canada Dept. of Mines, Mines Branch, No. 696. Pp. 107, pl. 9, figs. 9. Ottawa, 1929 (Dec.).

Geological Survey of Brazil: Bull. 36, Geologia de Folha de S. Joao d'el Rey (Est. de Minas Geraes), by A. I. Erichsen. Pp. 26, pls. 8, map. Bull. 37, Bacia do Rio Branco (Est. do Amazonas), by A. I. de Oliviera. Pp. 70, illus. 24, map. Bull. 39, Forcas Hydraulicas, 1927. Pp. 35, maps 7. Serv. Geol. e Min. do Brasil, Rio de Janeiro, 1929 (Dec.).

Geology of the McCalls Ferry-Quarryville District, Pennsylvania. By ELEANORA B. KNOPF and ANNA I. JONAS. Pp. 156, pl. 8, figs. 15. U. S. Geol. Survey Bull. 799, Washington, 1929. Outline of the geology of the Appalachian region; detailed general geology; excellent treatment of physiography and valuable contribution to study of metamorphism; nickel ore of the Gap mine, iron and chrome.

SCIENTIFIC NOTES AND NEWS

Geo. H. Garrey, who recently completed geological examinations for the Belmont Copper Corporation in Baker County, Oregon, and for Pierpont Mines, Inc., in Nevada, has returned to Philadelphia.

James S. Wroth has resigned his position as head of the potash explorations under the U. S. Bureau of Mines to take a private position.

Philip D. Wilson, formerly general manager of the South African Copper Company, has returned to the New York office of the American Metals Company after a trip to Northern Rhodesia.

J. B. Tyrrell was recently awarded the Charles P. Daly gold medal of the American Geographical Society. The presentation was made at Ottawa by Dr. Isaiah Bowman, who drew attention to his well known explorations in Northern Canada and his geological studies of that region. Dr. Tyrrell's study of the Kirkland Lake Gold Mining properties resulted in a shaft being sunk to 4,000 feet and the finding of rich ore bodies.

George Steiner has opened a Pacific coast office for geophysical work at Los Angeles under the direction of H. W. Rose.

M. J. Munn, of the Cosden Oil Company, is now in charge of the Little Rock, Arkansas, offices.

Geo. C. Stone has been visiting India, Singapore, and the east coast of Asia.

Orville E. Rhinehart and Charles T. Lupton have been engaged in mapping the Barker Dome and locating for the Black Hills Petroleum Company a well which is claimed to be the first commercial well in South Dakota.

The newly elected officers of the Oklahoma Geological Society are: President, J. T. Richards, Gypsy Oil Co.; Vice-President, R. M. Whiteside, Shell Petroleum Corporation; Secretary-Treasurer, R. D. Jones, Shell Petroleum Corporation.

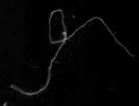
The Canadian Mining Institute held its 31st annual meeting at Toronto, March 5–7. This meeting kept up the reputation of its predecessors and every one, as they always do, enjoyed themselves. The papers of interest to geologists were: The Mimpkish Lake Copper Deposits, by H. C. Gunning; The Wilberforce Radium Deposits, by H. S. Spence; Gowganda Silver Area, by A. D. Campbell; Mineral Statistics of the Dominions; Limestone in Ontario, by M. E. Goudge; Gypsum in Canada, by L. Heber Cole; Lignite Deposits at Onakawana, Moose River Basin, by W. S. Dyer; Quantitative Microscopic Analysis and its Application to Mining, by J. E. Thomson; Geological Structure of the Southwestern Portion of Sudbury Basin, by E. S. Moore; Geology of the Pickle-Crow

District, by M. E. Hurst; Utilization of Pyrites for Acid Making, by H. Freeman; The Northern Rhodesia Copper Deposits, by Alan Bateman.

The annual meeting of the Society of Economic Geologists, scheduled for Charlottesville, Virginia, April 24–26, promises to be well attended and interesting. Some eighteen titles have been submitted. Sessions will start on Friday morning.

The 16th International Geological Congress organization is well under way. A permanent Organizing Committee has been appointed. W. C. Mendenhall, of the U. S. Geological Survey, Washington, D. C., has been made the Secretary-General. The Congress will be held in 1932, probably in June. Preliminary registration will take place in New York, and pre-Congress excursions will start from there. The sessions will be held in Washington. Post-Congress excursions will include some in Eastern and Mid-Western States and probably three Transcontinental excursions. The Transcontinental excursions will converge in California, where some sub-meetings and local excursions will probably take place.

The American Institute of Mining and Metallurgical Engineers held its 139th annual meeting in New York, Feb. 17–20, and had the largest attendance in its history. Sessions lasted four days. The usual sectional meetings took place. Of interest to geologists were the coal, petroleum, geophysical, and mining geology sessions. The mining geology papers were: The Pao Deposits of Iron Ore, Venezuela, by E. F. Burchard; The Status and Importance of Isostasy, by Wm. Bowie; Geology of the Parral Area, Chihuahua, Mexico, by H. Schmitt; Structure of Gold-Bearing Quartz in Northern Ontario and Quebec, by G. W. Bain; Solution Pressure as a Control in Ore Emplacement, by A. Wandke; The Economic Geology of the Britannia Mines, British Columbia, by F. Ebbutt and H. M. A. Rice; The Occurrence of Quicksilver Ore Bodies, by C. N. Schuette. Unfortunately most of the papers were read by title, so that the sessions were brief.

The National Research Council, Division of Geology and Geography, announces the founding of the Storrow fellowships by gift of Mrs. J. J. Storrow of Boston, to aid young men of outstanding ability to enter research work in geology or geography. Though candidates are presumed to have the equivalent of a bachelor's degree, in some cases awards may be made to men of special ability who are in need of further training before entering the research field. The stipend is from $1200 upward, according to conditions. Applications should be addressed to the Chairman, Committee on Fellowships, Division of Geology and Geography, National Research Council, B and 21st Sts., Washington, D. C.

The recently published 20-volume index (336 pages) of ECONOMIC GEOLOGY for 1905 to 1925, compiled by J. M. Nickles, may be obtained for $3.00 from W. S. Bayley, University of Illinois, Urbana, Ill.